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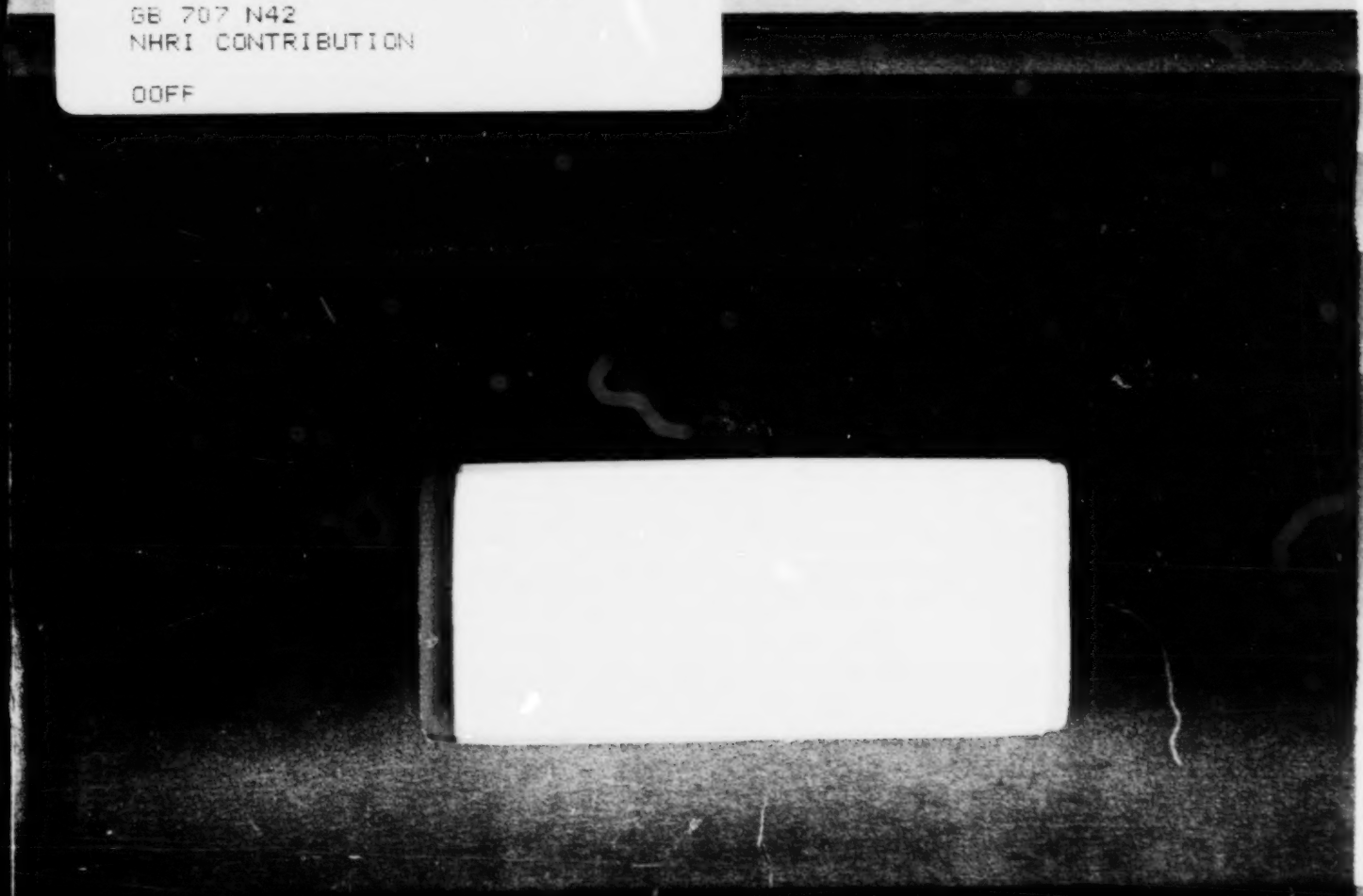

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SEDIMENT REGIME OF LAKES IN THE MACKENZIE DELTA

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ABSTRACT

During the summer of 1987, detailed hydrologic and sedimentation measurements were made on three lakes in the Mackenzie Delta near Inuvik. Due to the importance of sediments in carrying adsorbed hydrocarbon contaminants, this work on the spatial and temporal patterns of sediment deposition under different flow conditions improves our ability to predict and evaluate environmental impacts of hydrocarbon development in the Mackenzie Basin.

This work illustrates the large variations in regimes found in typical lakes. Sedimentation decreases with increasing lake sill elevation and distance from the main channels. For example, the mean sedimentation rates ranged from 1.3 mm for the lowest sill elevation lake to only .02 mm for the highest lake. Large spatial and temporal variations in this sediment input were found. At one lake, 67% of all sediment was input during the brief spring flood period, and 53% of all sediment was deposited in only 6% of the lake area.

Using these sedimentation data and published values of hydrocarbons adsorbed onto the suspended sediments in East Channel at Inuvik, the input of hydrocarbons into NRC, Skidoo, and South Lakes was estimated as 2, 363, and 620 g or 25, 961, and 996 $\mu g/m^2$ during 1987. Due to the scarcity of hydrocarbon data, these estimates must be viewed cautiously. Additional information on the timing or spatial distribution of these hydrocarbons in the study lakes is not available.

General remarks can be made concerning the input of hydrocarbon contaminants due to accidental spills. With a knowledge of the water level during a spill, the total number and area of lakes affected could be estimated and using the data on spatial variation of sedimentation, so can the lake areas most affected. This type of information has important implications for predicting the effect of hydrocarbon development on the lakes in the Mackenzie Delta.

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SEDIMENT REGIME OF LAKES IN THE MACKENZIE DELTA

1. INTRODUCTION

Increasing oil and gas exploration and production in the Mackenzie River Basin have raised concerns over the levels of contaminants, especially hydrocarbons, in the Mackenzie River and the role that sediments play in the transport and deposition of these hydrocarbons. This problem was noted by Bruce (1980) in a keynote address to an international symposium on hydrocarbons and halogenated hydrocarbons. More recently, the effect on fish and other wildlife has become an issue. Unfortunately, important aspects of this problem, such as the natural background levels, the sources, transport, and fate of contaminants in the Mackenzie River system are not well known.

Since the Mackenzie Delta is a major sink for sediments derived from the Mackenzie Basin, contaminants released into the Mackenzie River from shore-based hydrocarbon developments will be deposited, along with sediment particles, into lakes in the Mackenzie Delta. As a result, the delta lakes may be susceptible to hydrocarbon contamination. To predict the spatial and temporal patterns of contaminant deposition under different flow conditions, detailed information on the sediment regime of delta lakes is required. However, our knowledge of the complex

interactions between the hydrologic and sedimentary processes is not sufficient to evaluate impacts and to mitigate serious problems.

1.1 Objectives

The primary objective of this study is to describe and quantify the sedimentation regime of lakes in the Mackenzie Delta in order to better understand one of the major sinks for sediments and hydrocarbons derived from the Mackenzie Basin. This work will enhance our capabilities to provide scientific advice on environmental problems which may result from hydrocarbon development in the Mackenzie Basin. Specifically this report will:

(a) document the lake channel discharge and sediment regime over the entire spring/summer period;
(b) measure the sediment budget for three lakes in order to determine the mean sedimentation in each lake; and
(c) determine the spatial pattern of sedimentation in these lakes.

This report will present only a description and initial analyses of the data collected in 1987. Therefore, the results are preliminary and may be revised as ongoing analysis is completed. It must also be realized that these results are based on a single year's sedimentation data. Further work is required to document the annual variability of sedimentation rates in delta lakes.

1.2 Hydrocarbons and sediments

Hydrocarbons may enter a river system from natural seeps, from spills associated with exploration, production, transportation or consumption of oil and gas, or from contaminated airborne particulates. The chemical constituents of these hydrocarbons are complex and they vary depending on the source. Generally though, more than 75% of the original hydrocarbon is composed of paraffins (or alkanes), cycloparaffins, aromatics, and naptheno-aromatics (Bockris, 1977). The effect of these hydrocarbons on natural ecosystems is not well known, but previous studies have indicated that certain hydrocarbons are carcinogenic (ie. Crane et al., 1980). In most studies the n-alkanes and polyaromatic hydrocarbons (PAH) receive considerable attention. However, these only constitute a portion of the total hydrocarbon load.

Recent work has demonstrated conclusively that sediments (mineral and organic) play an important role in the transport of contaminants, including hydrocarbons, in fluvial systems (Allan, 1979 and 1986; Forstner and Wittmann, 1979). The factors controlling the adsorption onto, and the removal of contaminants from, these sediments is complex and unfortunately not well understood (Allan, 1986; Karickhoff et al., 1979). It has been well documented, however, that due to the high surface area of silts and clays (<62 μm), the majority of contaminants are adsorbed onto these fine-grained particles.

Once adsorbed onto the sediment, the fate of the contaminant is controlled primarily by the movement of the sediment particle. As a result, the fate of adsorbed contaminants is very different from those

contaminants in solution. A simple conceptual model of the geochemical cycling of these contaminated sediments was given by Eadie et al. (1983) and modified by Allan (1986). In a river system for example, sediments are transported downstream and may be deposited and undergo burial in slackwater areas, on the river bed, on floodplains, or in floodplain lakes. Once deposited, these sediments may be recycled during periods of higher flow velocity or by bioturbation, and will be transported farther downstream. This process of deposition and erosion may occur many times before the sediment particle enters long-term storage. The fine-grained portion of the sediment load, often referred to as the wash load, remains in suspension even under low-flow velocities. It is often assumed therefore, that once entrained, this material is not deposited within the river reach, but is transported directly from its source to long-term storage in a major receiving basin.

1.3 Sediments in the Mackenzie Basin

The Mackenzie, Arctic Red and Peel Rivers transport approximately 125 * 10^6 Mg/a of suspended sediment to the Mackenzie Delta (Table 1), with the Mackenzie River supplying approximately 70% of the total. This sediment is generally fine-grained, with 90% of the suspended load less than (D_{90}) 75 μm in size at the Mackenzie River at Arctic Red (Church et

Table 1. Reported values for sediment input to the Mackenzie Delta, and sedimentation rates in the Delta and the Beaufort Sea.

	Weight (Mg/a)	Depth (cm/a)	Comments	Source
Input to delta from Mackenzie, Peel, and Arctic Red	125×10^6	--	Adjusted from WSC data	Lewis (in prep)
	160×10^6	--		Brunskill et. al (1973)
	92×10^6	--	Based on WSC data	Hirst et. al. (1981)
Sedimentation in Delta	153×10^6	1.02	max value Sedimentation on upper subaerial plain ($10,000$ km^2)	Hirst et al. (1987)
	64×10^6	.43	min value	
	125×10^6	.69	Assuming all sediment entering delta deposited over $12,000$ km^2 area	
	--	.51	Sed. over 7,000 yr period at NRC Lake site	Johnston and Brown (1965)
Sedimentation in Beaufort Sea	220×10^6	1.00 .22	Based on record of Middle Channel above Napoiak adj. by 1.1 with 50% of sedimentation in water < 10 m ($10,000$ km^2) and remainder of sedimentation in water 10 to 200 m ($50,000$ km^2).(specific gravity = 2.5).	Thomas et al (1986)
	100×10^6	--	Calculated as total output of the Mackenzie River but noted that deposition on delta may limit amount actually reaching the ocean	Milliman & Meade (1983)
	--	.1	Estimated from radio carbon data as mean for shelf (area depth representative for not given) over last 8,000 years.	Thomas et al. (1986)
	125×10^6	.14	Assuming all sediment entering delta deposited on Beaufort shelf ($60,000$ km^2)	

Note: density of 1.5 Mg/m^3 used unless noted otherwise.

al., 1987). Farther upstream the particles are larger, with D_{90} of 170 μm for the Liard River near the mouth. Along the main stem of the Mackenzie River therefore, the majority of the suspended load is in the size range having a large sorptive capacity for contaminants.

The major source of the sediment discharged by the Mackenzie River is the Liard River. B.C. Hydro (1985) for example, estimated that the sediment load of the Liard River is equal to 40% of the total suspended sediment at the Mackenzie above Arctic Red. Very little is known about the provenance of the remaining sediment discharged from the Mackenzie River at Arctic Red River, and, as Carson (1988) notes, the "major part of the Mackenzie's input to the Delta is thus from sources whose contributions have yet to be assessed". Much of it must originate from the left bank tributaries draining the Mackenzie Mountains, but the magnitude is not well known. Another potential supply is the erosion of fine grained bank material along the Mackenzie River. Its relative importance is also not known. The portion of the Mackenzie River upstream of the Liard confluence supplies little sediment because of the control of Great Slave Lake and the right bank tributaries of the Mackenzie main stem are also sediment deficient. This is primarily because of geologic controls.

The main sinks for sediment discharged from the Mackenzie Basin are the Mackenzie Delta and the Beaufort Sea, but the relative importance of each is not known. Hirst et al. (1987) quoted a study by Church (1981), which discusses two extreme possibilities. In the first case, the sediment delivered to the delta is deposited and enters long-term storage

in the delta. The sediment delivered to the Beaufort Sea is derived from bank erosion in the delta. A second possibility is that most sediment is transported directly to the sea, with some short-term deposition on point bars, but in general only a small portion is deposited directly on the delta surface. Church (1981) suggested that hypothesis two is correct, but again there is little data to support either. A third scenario is for a more complex situation intermediate between the above two extremes, with significant long- and short-term storage in the delta.

Of the information required to support any of these hypotheses, the sediment input to the delta is best known. The most detailed analysis was carried out by Lewis (in prep), who estimated the suspended flux from the Mackenzie, Arctic Red, and Peel Rivers as $125 * 10^6$ Mg/a. This is approximately midway between the extreme estimates of sediment input shown in Table 1. The major errors associated with these data are, first, the suspended load during spring break-up is not well known. Second, the bed load is not included. Based on estimates by Church et al. (1987) for the Mackenzie River at Norman Wells, bed load may be approximately 1.5 to 3% of the suspended load.

The proportion of this sediment which remains within the Mackenzie Delta has been estimated only by a single study (Hirst et al., 1987). Using measured sedimentation in different geomorphological units, and weighting for areal coverage, they reported a mean sedimentation rate of between .4 and 1 cm/a over the upper subareal delta (Table 1). This is similar to the mean sedimentation rate of .5 cm/a over the last 7000 years at NRC Lake (Figure 1) as derived from a single radiocarbon date of wood buried at the 38 m level (Johnston and Brown, 1965). This is the

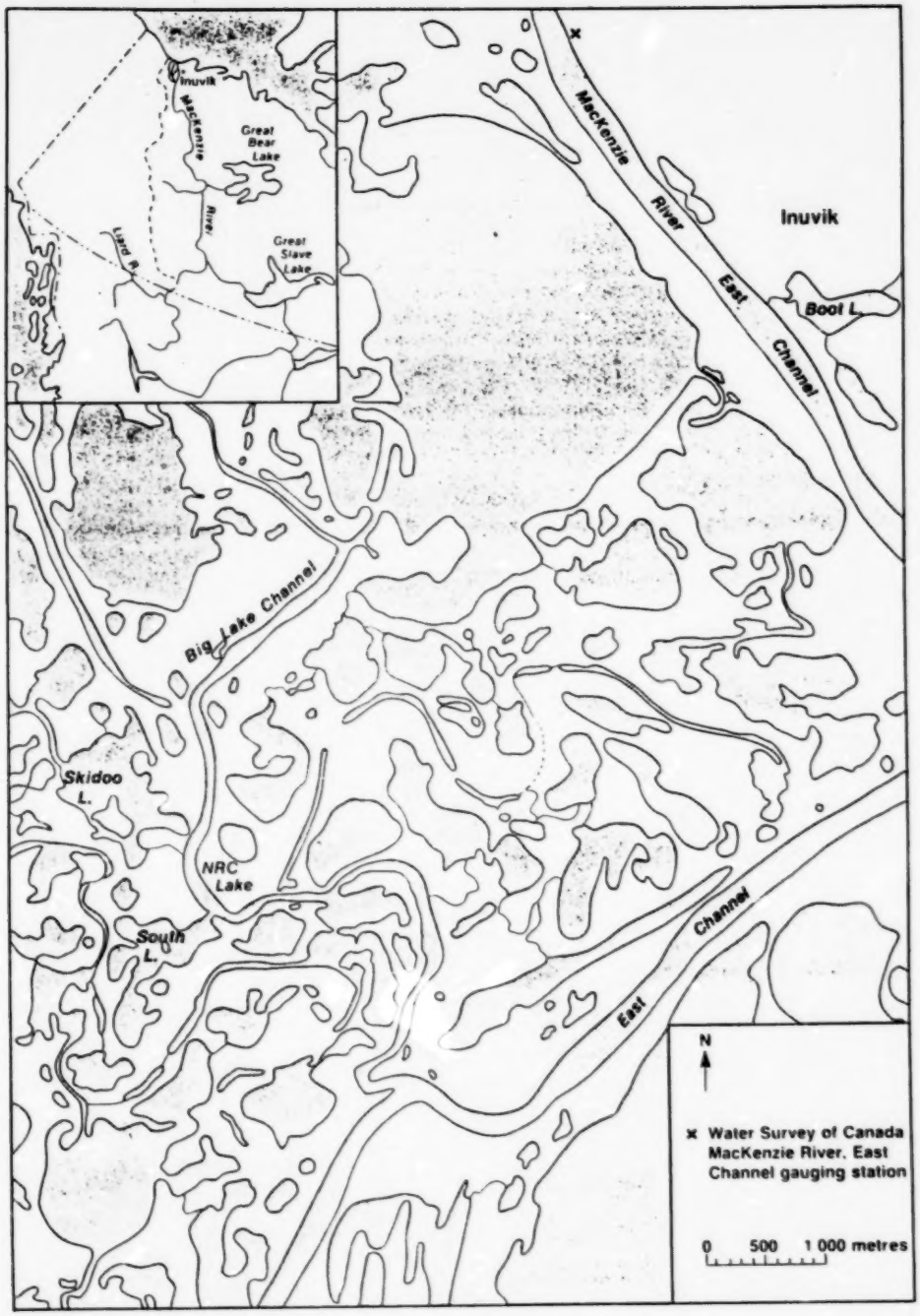

Figure 1. Location of study lakes near Inuvik, N.W.T. Skidoo Lake, NRC Lake, South Lake and Big Lake Channel are unofficial place names.

only estimate of long-term aggradation in the Mackenzie Delta. Since these values are close to the estimate of .69 cm/a which would occur if all sediment was deposited within the delta (Table 1), it seems to substantiate hypothesis number 1 discussed above. However, due to the paucity of sedimentation data that Hirst et al. (1987) used, compared to the large spatial variation in sedimentation and erosion on the delta surface, and the single value derived from Johnston and Brown (1965), these results must be viewed skeptically.

The problems with these sediment data become more apparent when estimates of the Beaufort Sea sedimentation rates are reviewed. For example, using data for the sediment output of Middle Channel, Thomas et al. (1986) estimated the Mackenzie input to the Beaufort Sea at nearly twice the value given by Lewis (in prep.) as the input to the delta (Table 1). The value given by Thomas et al. (1986) was also considerably higher than the estimated long term sedimentation rate in the Beaufort of .1 cm/a over the last 8000 years (Table 1). Thomas et al. (1986) suggested that this "may reflect that current sedimentation rates are higher than the average calculated for the past 8000 years". Note again that the value of .1 cm/a is similar to the sedimentation which would be expected if all the sediment input to the delta was deposited on the Beaufort Shelf (Table 1).

In light of these obvious problems, the relative importance of the Delta and Beaufort Sea as sediment sinks for sediment and hydrocarbons derived from the Mackenzie Basin are uncertain. Certainly, more data is required in order to determine the sediment balance of the Mackenzie Delta and the relative importance of short- and long-term storage.

Though the above section illustrates that the overall sediment balance of the delta is not well known, the available data do suggest that significant sedimentation occurs in the delta lakes. For example, delta lakes cover between 5 and 50% of the delta area (Mackay, 1963), with a total of 25% (Lewis, in prep.), and preliminary work has shown sedimentation rates of between .03 and 1.05 cm/a in the deepest sections of the lake basins (Cordes and McLennan, 1984). These sedimentation rates have implications for the sediment balance of the delta and the physical and biological condition of these lakes. However, there are large gaps in our knowledge of lake sedimentation. For example, though the spatial variation in sedimentation is large, there are no detailed data on the range of sediment rates within lakes, the sediment balance of delta lakes, or mean lake sedimentation. In addition, only one preliminary study (Cordes and McLennan, 1984) has looked at the influence of lake sill elevation, or the location of lakes relative to the main channels, on lake sedimentation.

1.4 Hydrocarbons in the Mackenzie River

There are a number of sources of natural hydrocarbons in the Mackenzie Basin, some of which may be adsorbed onto sediments and deposited in the Mackenzie Delta or Beaufort Sea. The Athabasca Tar Sands, for example, introduce significant amounts of hydrocarbons through seeps in the river banks, but the majority of this material is deposited

in Lake Athabasca or Great Slave Lake. Natural seeps also occur in the Mackenzie River near Norman Wells (Bone and Mahnic, 1984).

Anthropogenic sources include oil production and transportation from the Norman Wells oil fields and natural gas production in the Liard River basin. There is ongoing oil and gas exploration along the Mackenzie Valley and in the Mackenzie Delta area. There is also the potential that hydrocarbons which have accumulated in the Mackenzie River bed could be disturbed by dredging activities. In addition, hydrocarbons may enter the Mackenzie River in conjunction with barge traffic on the river or highway traffic within the basin. Polyaromatic hydrocarbons, which are produced primarily by the combustion of hydrocarbons, may be introduced to the Mackenzie Basin through airborne contamination.

In an initial attempt to determine the background levels of hydrocarbons in the Mackenzie River, and to determine the relative importance of different natural sources, Peake et al. (1972) obtained water samples throughout the Mackenzie Basin. They found that the levels of n-alkanes were generally below the detection limits of 0.25 μg/l in water and ranged from 1 to 9.4 μg/g in the sediment. The highest concentrations of hydrocarbons were found in the silts of Lake Athabasca and the Mackenzie Delta near Inuvik. In a more recent study aimed at determining the relative importance of anthropogenic sources, Nagy et al. (1986, 1987) found that levels of n-alkanes varied from .141 to 3.759 μg/g of sediment, while the PAH levels were generally lower, ranging from .052 to 1.523 μg/g of sediment. The spatial distribution of the two types of hydrocarbons was similar with high initial values in the Mackenzie upstream of the Liard River, decreasing values farther downstream, and

then increased amounts below Fort Good Hope. An initial interpretation suggests a biogenic origin for much of the n-alkanes (Peake et al 1972; Nagy et al., 1986), although natural seeps may be responsible for the higher n-alkanes in the vicinity of Norman Wells and for the PAHs observed at two of the study sites (Nagy et al., 1986). Unfortunately the limited data set makes the interpretation of the Peake et al. (1972) and Nagy et al. (1986) information difficult. Certainly, more information is required to understand the temporal and spatial variations of hydrocarbons in the Mackenzie River, and the amount of hydrocarbons which occur in the delta lakes.

2. STUDY AREA

Field work was carried out in the eastern portion of the Mackenzie Delta 5 km southwest of Inuvik at NRC Lake, South Lake, and Skidoo Lake (Figure 1). In addition, less detailed work was conducted in a series of other lakes in the Skidoo Lake system (Figure 2). During the period 1984 to 1987 hydrologic studies were carried out at these sites, and in 1987 the sedimentologic work was performed.

These lakes are located in the zone of continuous permafrost, but the ground beneath the lakes is completely unfrozen (Johnston and Brown, 1964). The vegetation surrounding the lakes is characterized by a white spruce forest with a dense underbrush of willows and alders.

The hydrologic regime of lakes in the Mackenzie Delta is dominated by flooding by the Mackenzie River, with the frequency and duration of

Figure 2. Aerial photograph of the study sites. Rabbit Ears Channel is an unofficial place name. The lighter coloured lakes have higher suspended sediment concentrations. Also shown are the main channel entrances for the Skidoo Lake system (▲).

lake flooding controlled by the lake sill elevation, where lake sill elevation is defined as the highest elevation along the channel thalweg connecting the lake and main channel. If a connecting channel does not exist, the sill is considered to be the lowest elevation in the levee separating the lake and main channel.

NRC Lake is a moderate sill elevation lake, while Skidoo and South Lakes have sill elevations close to the minimum for this part of the delta. These variations produce a significant difference in hydrologic regime and therefore sedimentation regime.

NRC Lake is approximately 0.069 km^2 in area, with a mean depth of 0.88 m and a maximum depth of 1.6 m in mid-summer (Figure 3). Skidoo and South Lakes are larger, with areas of .62 and .38 km^2 respectively and maximum depths of 4 m (Figures 4 and 5). Both Skidoo and South Lakes have prominent deltas where the small connecting channels enter into the lakes.

South Lake has a single channel connecting it to the main channel, while Skidoo Lake has two connecting channels and is part of a large lake system (Figure 2). This lake system is connected to Big Lake Channel through Skidoo Channel East, to East Channel to the South East and to Rabbit Ears Channel to the south and west (Figure 2).

NRC, Skidoo, and South Lakes were chosen primarily because they represent a range of lake conditions typical of the central Delta. In addition, since they are close to Inuvik, the long-term water level data from Water Survey Canada (WSC), Mackenzie River East Channel, can be applied to the study lakes. These provide important data on the hydrologic regime of the lakes. The proximity to Inuvik allows easy

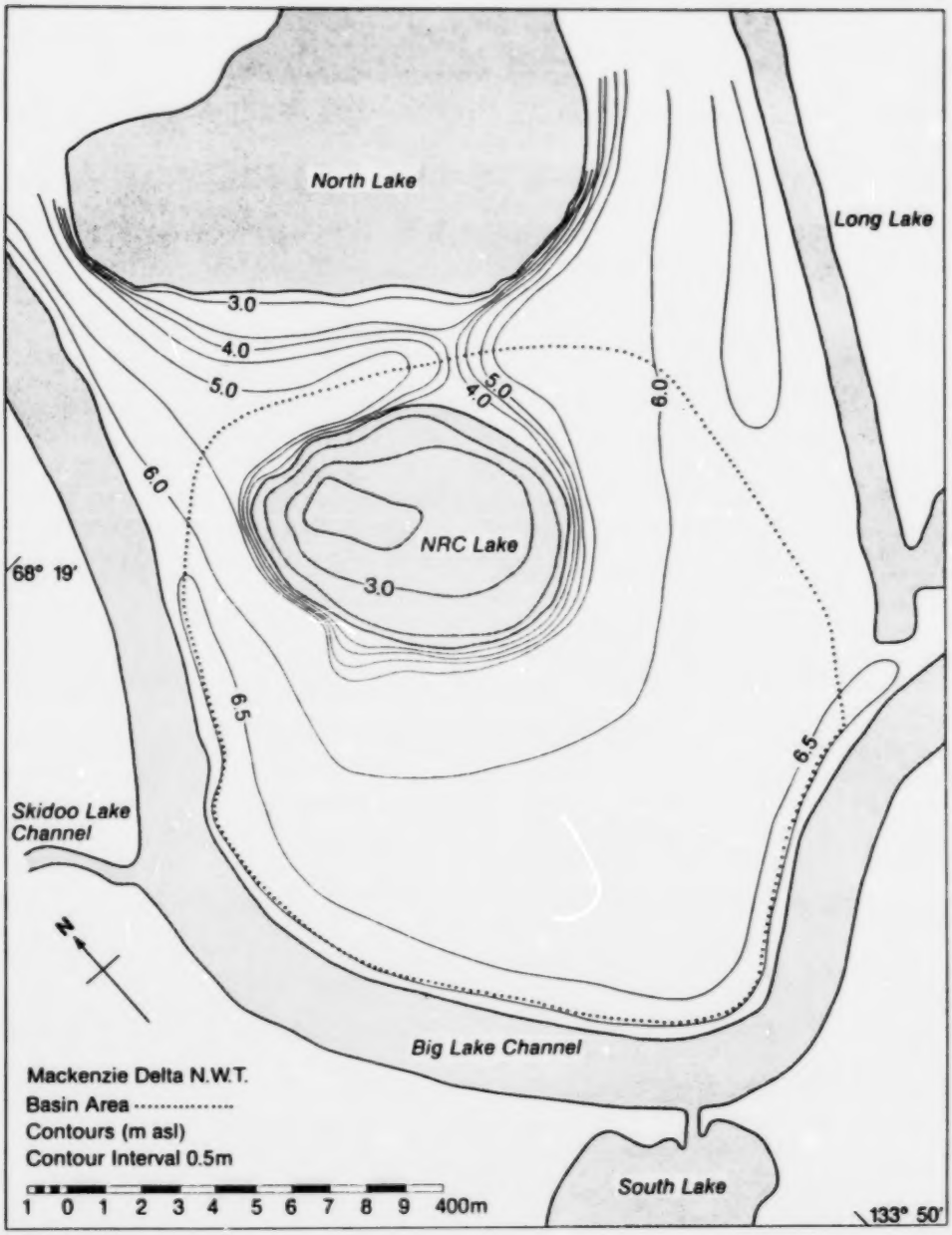

Figure 3. Topographic map for NRC Lake. All names shown are unofficial place names. Note that all contours are in m asl.

Figure 4. Bathymetric map for Skidoo Lake, Next Lake and New Lake. All names are unofficial.

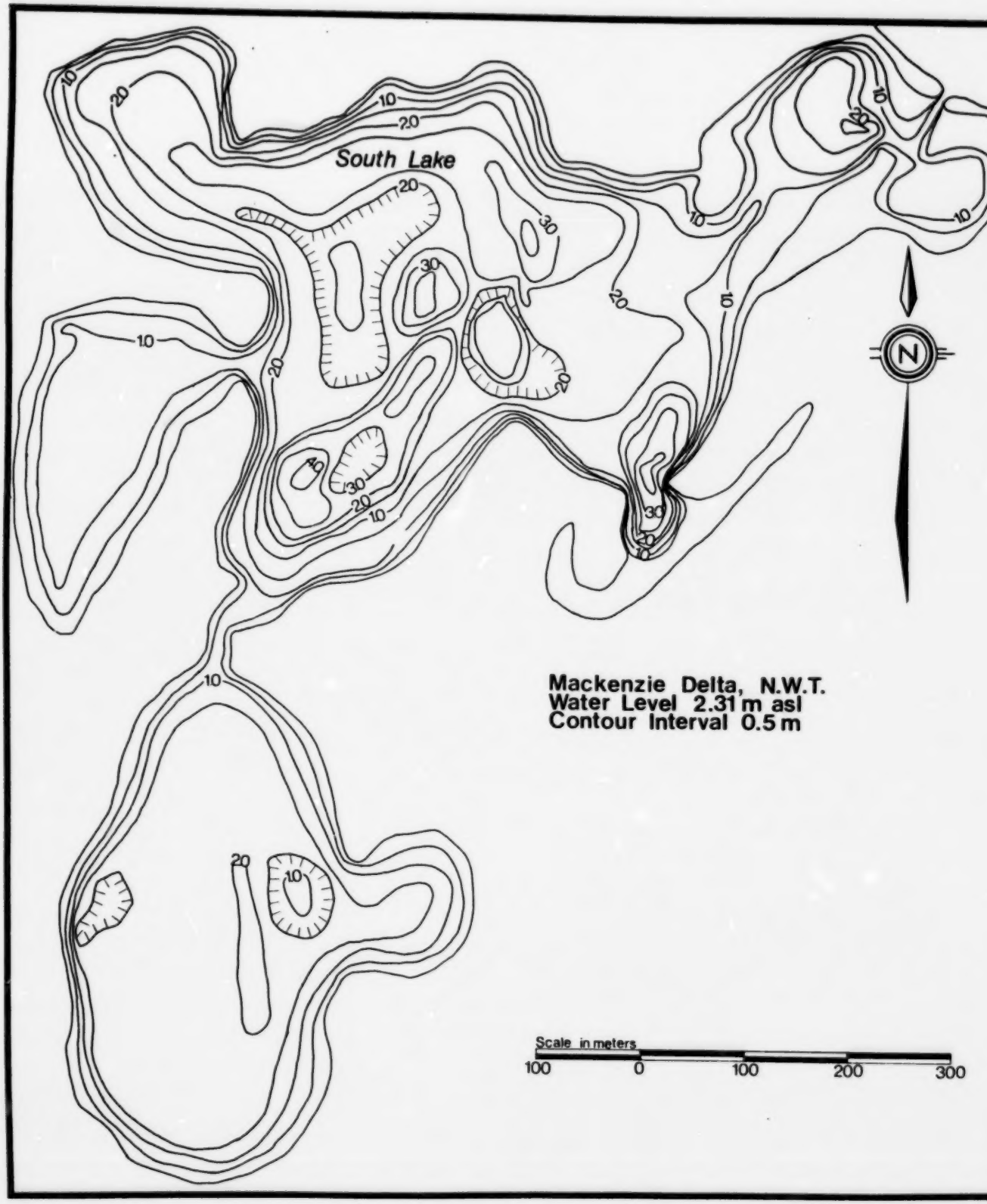

Figure 5. Bathymetric map for South Lake.

access to the lakes for monitoring throughout the spring and summer period.

3. FIELD METHODS

Hydrology

In order to obtain water balance data for the study lakes, micrometeorological and hydrological measurements were made from an instrument platform near the centre of NRC Lake and from Skidoo Lake. Lake evaporation was determined using the Priestley-Taylor method (Marsh and Bigras, 1988) with a Campbell CR21 or Omnipod data logger recording air temperature, net radiation, and bed and water temperature. Water input to the lake was calculated by recording precipitation directly to the lake surface, and from run-off from the surrounding basins. Channel discharge into and out of the lakes was measured every two days at the four channel sites. This allowed a determination of a rating curve of discharge versus lake stage for NRC Lake. However, since the South and Skidoo Lake channels reverse flow direction depending on the relative levels of the lake and main channel, a rating curve could not be obtained for them. To overcome this problem, small recording current meters, which measured flow velocity, direction, and water depth, were deployed at the South and Skidoo Lake channel sites (Figures 6 and 7). The manual discharge measurements were used to convert the recording current meter measurement of point velocity to mean cross sectional velocity. These

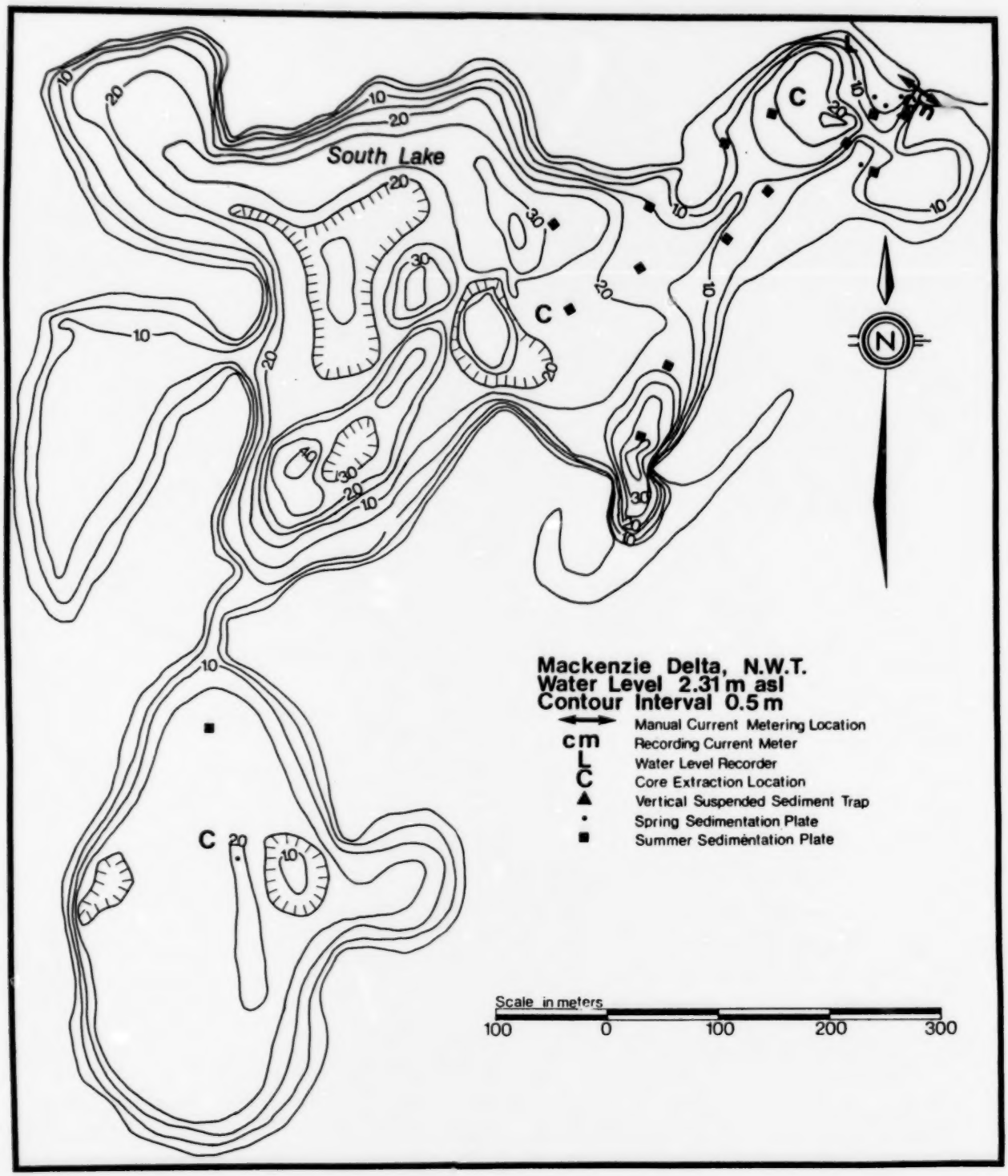

Figure 6. Instrument locations in South Lake.

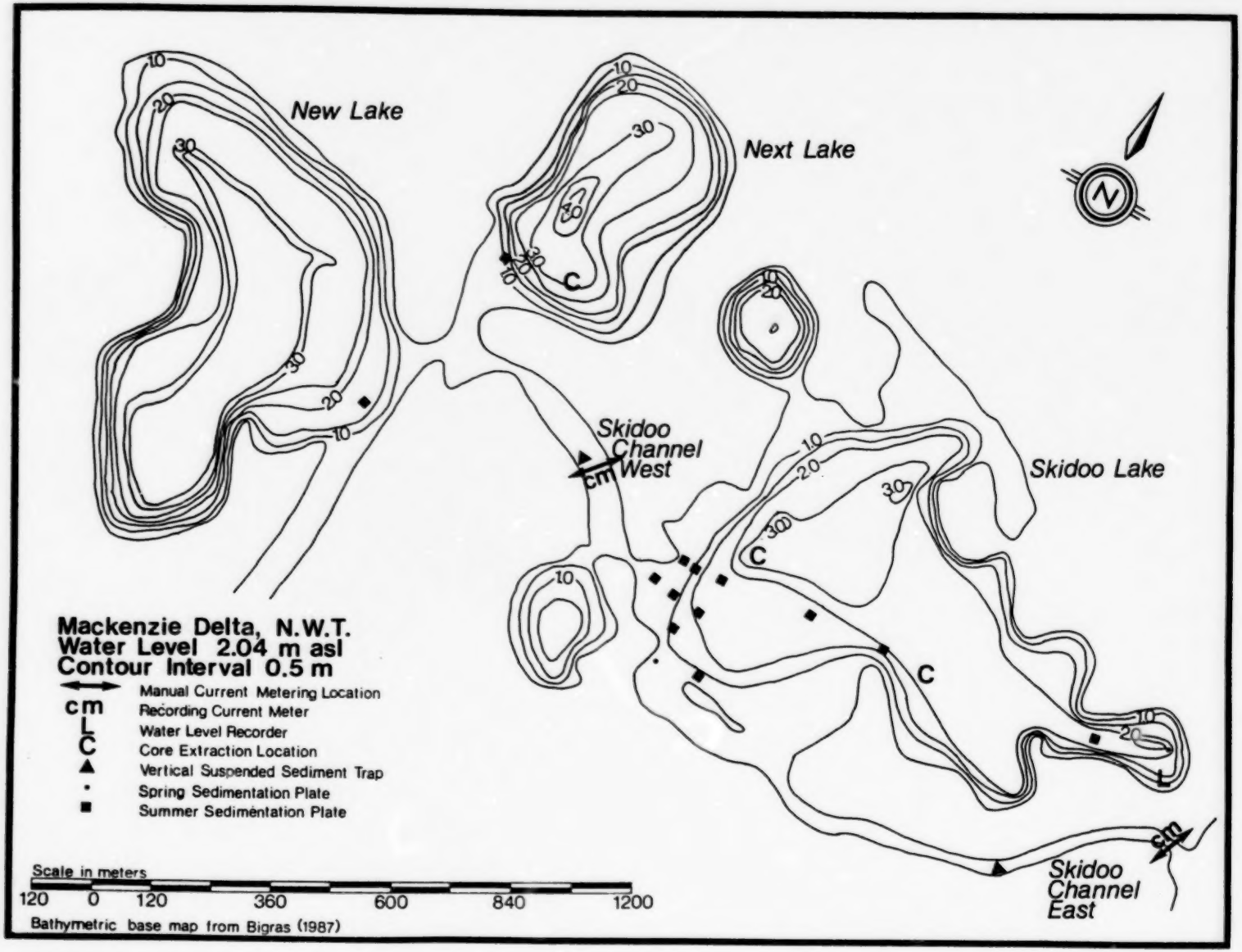

Figure 7. Instrument locations in Skidoo Lake.

values were multiplied by the channel cross sectional area to obtain channel discharge. The hourly values of discharge were then summed to obtain daily discharge.

During the spring flood period, when daily discharges were not measured, discharge was calculated from the change in lake storage. For the remainder of the summer, the manual discharge measurements were used for periods when the recording current meters were not operating.

The 25 years of water level data for East Channel at Inuvik, which is available from The Inuvik Scientific Resource Center and WSC, were analyzed to determine the hydrologic regime of these delta lakes. The details of this procedure are given in Marsh and Hey (1988).

All water levels reported in this report are referenced to a bench mark (IWD 8) established on East Channel by McElhanney (1983). This bench mark, surveyed using Doppler and inertial techniques, is referenced to mean sea level and has a reported accuracy of +/- 0.53 m at the 95% confidence level (McElhanney, 1983).

In order to determine the representativeness of the study lakes, the sill elevations of 132 lakes in the study area were determined (Figure 8). This was done primarily from measurements of main channel water level, in conjunction with aerial observations of the timing of lake flooding during the period of rising stage in late May and early June. These measurements were then checked by ground surveying of 14 lakes. These data suggest that sill elevations determined from the aerial observations are within +/- 0.5m of the ground survey measurements. Details on the measurement of lake sills are provided in Marsh and Hey (1988).

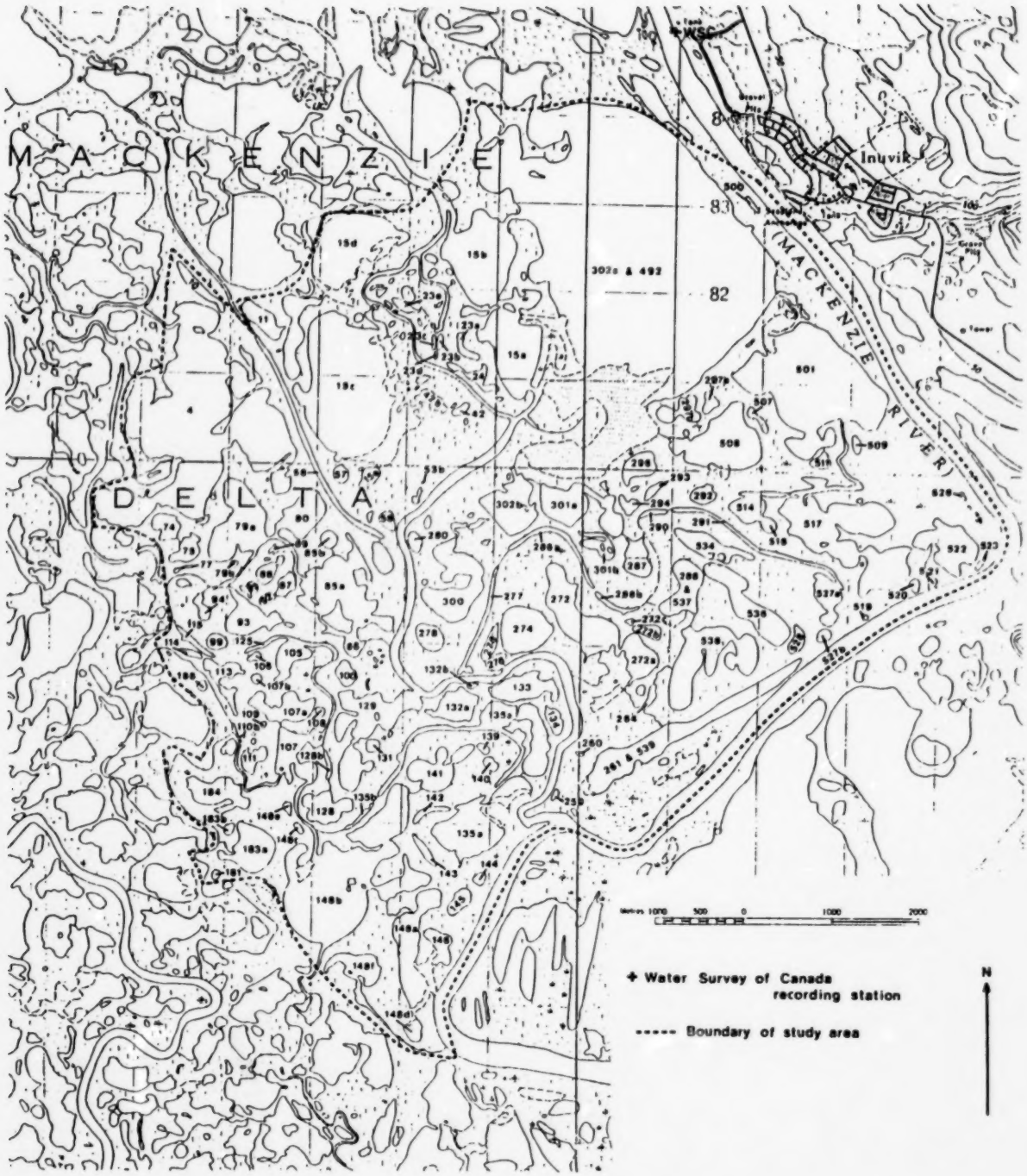

Figure 8. Sill elevations were determined for all the numbered lakes within the study area near Inuvik.

Sediment

Sediment movement was measured at NRC, South (Figure 6), and Skidoo Lake (Figure 7) channel sites. Suspended sediment samples were obtained at each site during the spring break-up, when the channels were partially ice covered, using grab samples taken from a helicopter. Once boat travel was possible, vertical integrated samples were obtained every two days using the US DH-48 suspended sediment sampler. A similar procedure was used at NRC Lake. Bedload transport was measured at Skidoo Channel East using a Bogardi bed material sampler.

A number of times during the summer, detailed measurements of vertical, cross channel, and hourly variations in suspended sediment concentrations were taken. These demonstrated that a single measurement of suspended sediment concentration was representative of the daily mean.

In order to determine sediment concentrations, a known volume of the sample was filtered through pre-dried and weighed Whatman GFC filter papers with a nominal pore size of 1.2 μm (Fischer Scientific, 1987). The sediment concentration was determined from the dry solid weight divided by the sample volume. The resulting suspended sediment concentrations were graphed and concentrations for days between measurement days were determined from the graph.

The daily loads were calculated for each lake channel for the study period as

(1) $L = Q\,C + B$

where L is the daily load (kg), Q is daily discharge, C is suspended sediment concentration, and B is the bed load. The annual sedimentation rate for each lake was then calculated as

$$(2) \quad S = \sum_{i=1}^{n} L_i \; / \; (\rho A_L)$$

where S is the sedimentation rate in mm over the total lake area A_L , L_i is the daily load from day 1 to n, and ρ is the sediment density. An average density of 1210 kg/m^3 was used as calculated from sediment cores extracted from the study lakes.

As a check on the accuracy of the calculated sediment budget, three other methodologies were employed. First, sedimentation plates were set at representative sites within the lake basins. Emphasis was placed on the areas near the mouths of connecting channels, where the sedimentation rate was expected to be highest. Of the 12 small, flat, round aluminum plates installed in late winter, only three survived the ice movement associated with break-up. During the open water season, .25 m^2 metal sheets with attached floats were placed on the lake beds. Of the 30 installed, 20 were retrieved in the fall and 10 were lost due to the extensive equisetum growth near the lake deltas. Using these measured sediment depths and measurements of suspended sediment distribution within the lake, the sedimentation depths were contoured and the average

sediment depth over the lake determined. Though these data are just for the summer period, they provide a good indication of the spatial distribution of the annual sedimentation within the lakes.

The second check of the sediment budget was provided by vertical suspended sediment traps adapted by Kenney (1987) from his original design (Kenney, 1985). The traps consisted of vertical settling chambers made from PVC pipe with a single sampling hole at the midway point of the sampling chamber. Since measurement of the vertical suspended sediment concentration showed no gradient, as is normal for rivers where wash load dominates, this single sampling hole provided a good measurement of the mean suspended sediment concentration. The samplers were installed on metal poles with an adjustable foot and attached to a permanent rod embedded in the channel. Three traps were installed at each site with one trapping sediment flowing into the lake, one trapping sediment flowing out of the lake, and one standard sampler trapping sediment flowing in both directions. The sediment was trapped and retained in 100 mL Nalgene bottles. The bottles were changed periodically, the sediment freeze dried and the weights recorded. The lake sedimentation rate was then determined as

$$(3) \quad S = W (A_C / A_S) / (\rho A_L)$$

where S is the sedimentation rate in mm over the lake area A_L, W is the difference in the inflowing and outflowing weight of material caught by the samplers, A_C is the mean channel cross-sectional area over the

sample period, A_S is the cross-sectional area of the sampler hole, and ρ is the sediment density.

The third check on the sediment budget was obtained by ^{137}Cs dating of sediment cores obtained from the lake beds. This method provides an estimate of the total sedimentation which has occurred since 1963. A sampler, comprised of a 10 cm diameter core tube, was used to obtain approximately 50 cm long cores from two locations within each lake. The cores were sliced in the lab at 1 cm intervals, then freeze-dried. ^{137}Cs concentrations were derived using a germanium-lithium scintillation counter.

The analysis of the ^{137}Cs dating and data from the suspended sediment traps is still ongoing, and the results will not be discussed in the present report.

4. LAKE SILL ELEVATIONS

Lake sill elevations range from about 0.0 m asl up to nearly 6 m asl during the summer (Figure 9), with a mean of 3.24 m asl and a standard deviation of 1.20 m. During the spring break-up period, however, the sill level is raised due to the presence of ice and snow dams in the small connecting channels. As a result, the mean effective spring sill level is 3.92 m asl, about 0.68 m higher than in the summer, with a standard deviation of 0.90 m (Figure 9). The study lakes, NRC, South, and Skidoo have sill elevations of 4.077, 2.363, and 2.363 m asl respectively in the spring, and 3.813, 1.272, and 1.272 m asl respectively in the summer.

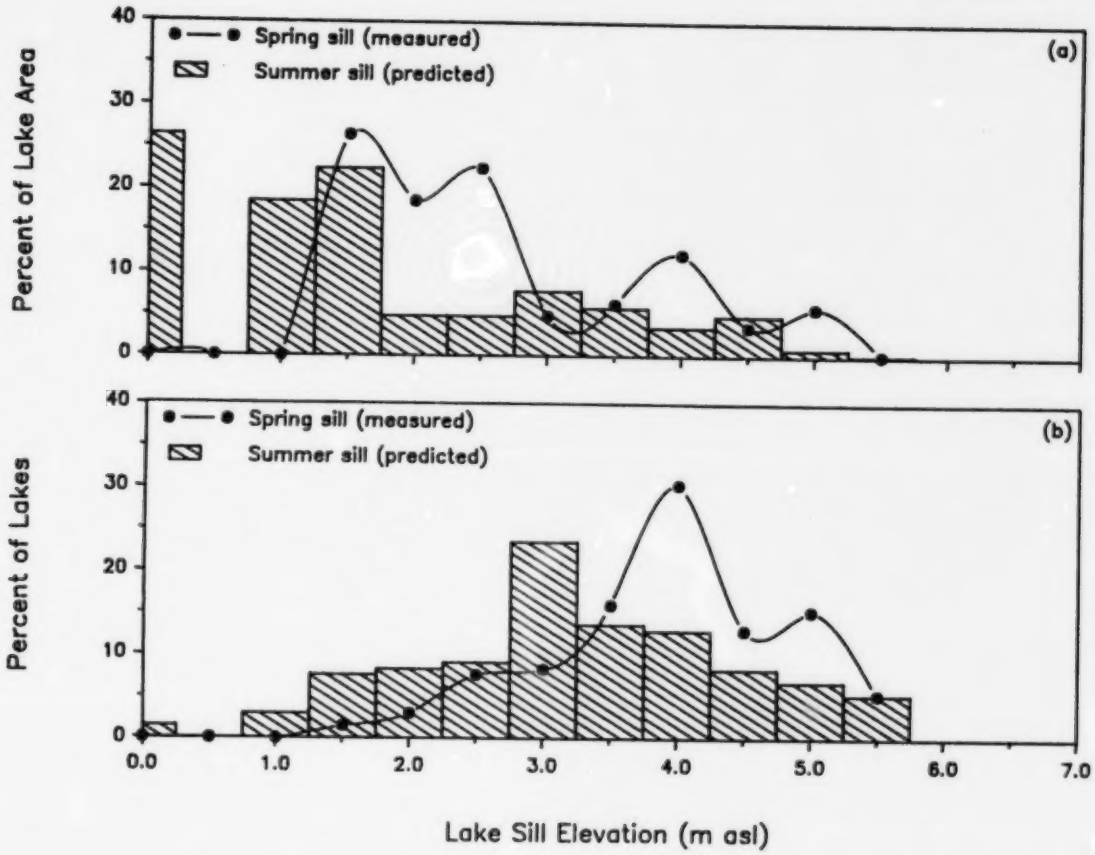

Figure 9. Spring and summer sill elevations for lakes in the study area, versus the percent of the number of lakes and the percent of lake area.

These data show that delta lakes occur over a continuum of elevations from sea level up to the levee height of 6 m reported by Mackay (1963) for this area of the delta. This implies that in terms of lake flooding, there is a continuum of hydrologic regimes from the lowest to highest elevation lakes. It would also be expected that a corresponding continuum of sedimentalogic regimes should exist.

An important feature of these delta lakes is that the few low sill elevation lakes cover a large portion of the total lake area. While the large number of higher elevation lakes are small in size and cover only a small portion of the total lake area (Figure 9).

5. LAKE HYDROLOGIC REGIME

The hydrologic and sedimentalogic regime of delta lakes is controlled primarily by the Mackenzie River, which adds significant amounts of water and sediment to them. The general water level regime for the Mackenzie River at East Channel is shown in Figure 10.

In early May, water levels increase dramatically from their late winter lows due to snow-melt in the southern portions of the basin and the occurrence of ice jams in the main channels of the Mackenzie Delta. After the spring peak, water levels drop rapidly, followed by a long period of gradually declining levels, with rain-induced peaks superimposed upon the flow regime. This water level pattern continues until after freeze-up in late September or early October. By January, the regime has changed considerably, with little variation in level.

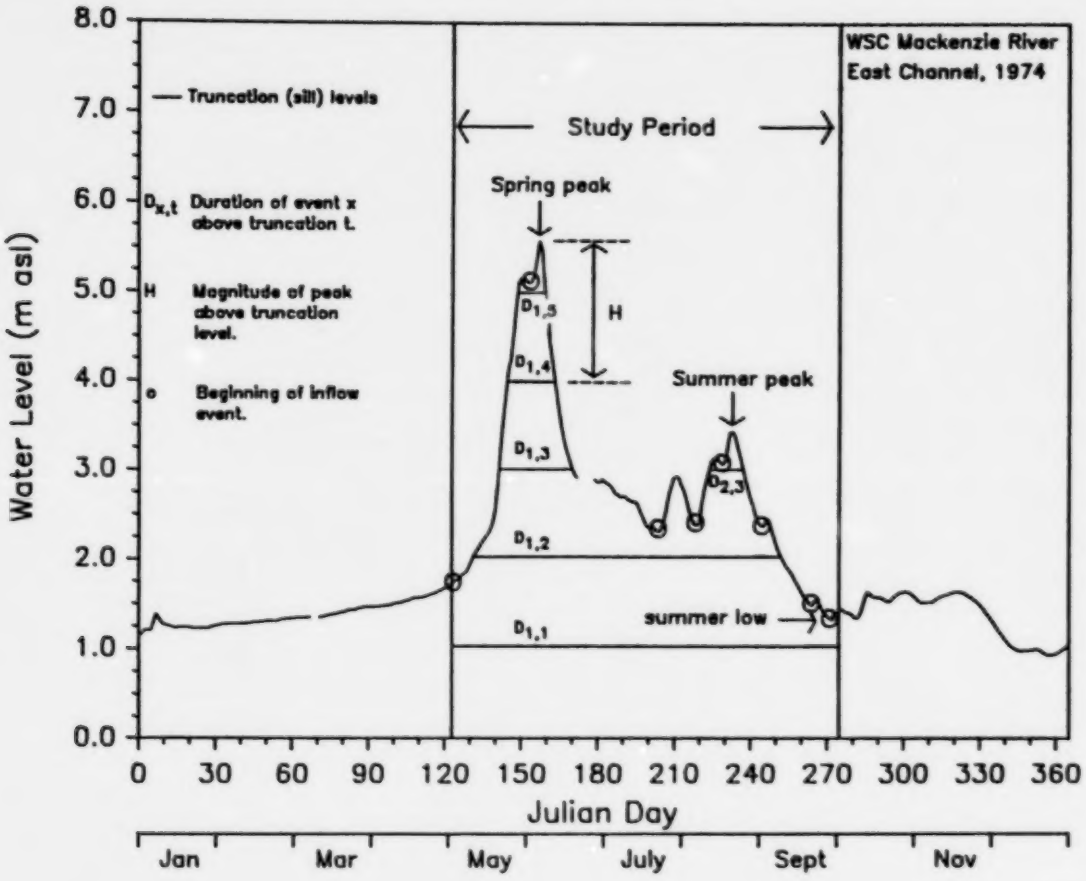

Figure 10. Typical hydrograph for Mackenzie River East Channel at Inuvik.

The exchange of water and sediment between a lake and a main Mackenzie River channel is controlled by the lake sill elevation. When the main channel level is above a lake's sill, water may be exchanged between the lake and main channel; with flow into the lake during periods of rising main channel stage, and out of the lake during falling stage. Due to the low water slope in the lake channels, the lake and channel level are similar during the period when the main channel level is above a lake sill.

The dominance of flooding is shown in the water balance for NRC Lake (Table 2). Note that the channel discharge (Q_{in} ,Q_o) dominates both the inputs and outputs to the lake. For lakes with different sill elevations, most of the water balance terms would be similar to those of NRC Lake, but the channel discharge would vary greatly. In general, with increasing sill level the channel discharge (both into and out of the lake) would decrease.

The frequency of lake flooding depends on the lake sill elevation and the season. During the spring period, peak East Channel water levels range from 4.298 to 7.820 m asl over the period of record, with a mean of 5.636 m asl (Figure 11). In 1987, the peak water level of East Channel at Inuvik was approximately 5.5 m asl. Given the range of spring sill elevations (Figure 9), the return period of lake flooding ranges from annually for lakes with spring sills of less than or equal to approximately 4 m asl (67% of all lakes), to less than annually for the remaining lakes (33% of all lakes). The highest sill elevation lakes flood every 4 years on average (Figure 11).

Table 2. Water balance for NRC Lake in 1985, where P is precipitation onto the lake surface, Q_{sp} and Q_s are suprapermafrost ground water and surface flow respectively from the surrounding basin into the lake, Q_{in} and Q_o are channel discharge into and out of the lake, Q_{sb} is groundwater flow in the talik beneath the lake, E is evaporation from the lake surface, ds/dt is change in lake storage, and e is an error term. All terms are in mm.

	Inputs					Outputs			Error
Date	P	Q_{sp}	Q_s	Q_{in}	Q_{sb}	Q_o	E	ds/dt	e
May 21 - June 9	5	0	0	2578	0	-2113	0	465	-5
June 9 - Aug 4	22	9	239	0	0	-579	-185	-437	56
Aug 4 - Sept 1	4	0	0	0	0	0	-60	-62	-6
Total	31	9	239	2578	0	-2692	-245	-34	45

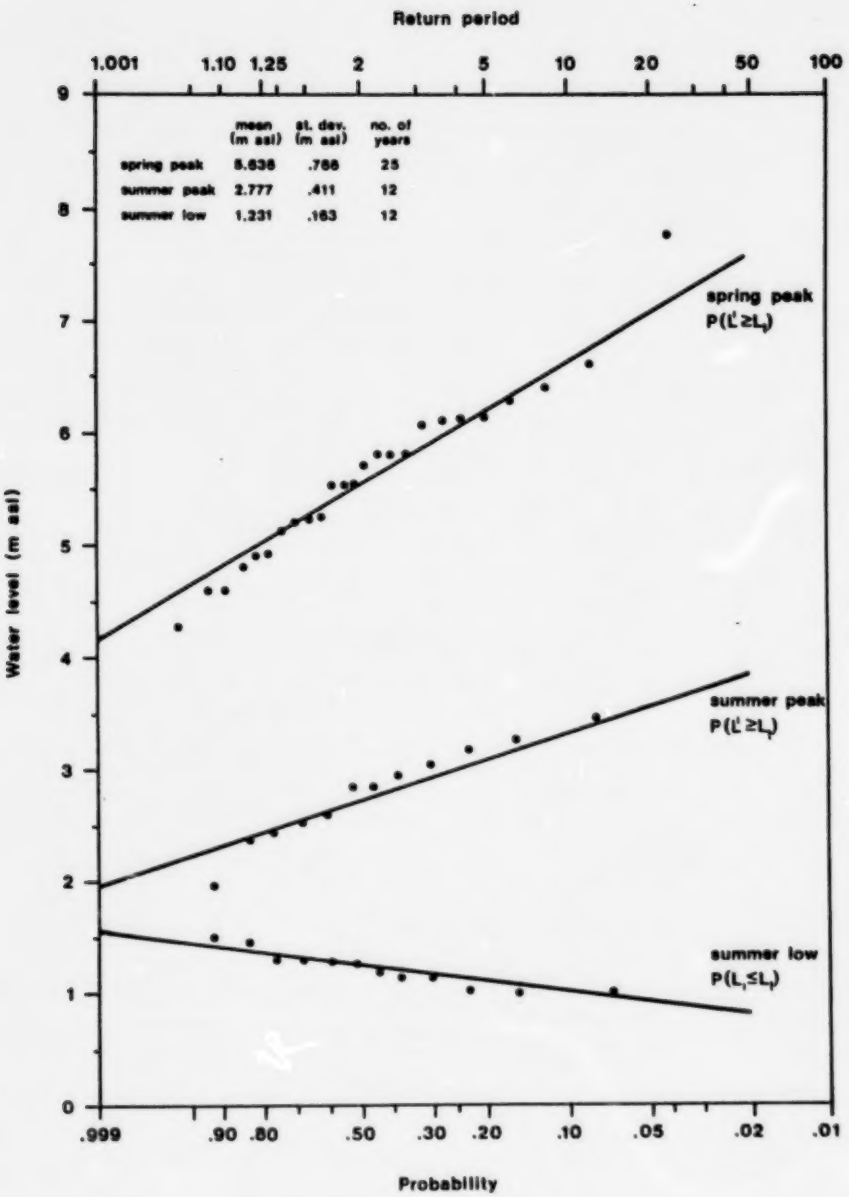

Figure 11. Return periods of extreme spring and summer peak levels, and summer low water levels. This graph may be interpreted as the return period of water levels exceeding or dropping below a given lake sill elevation.

During the summer period, water levels are consistently lower, with a mean peak level of only 2.777 m asl (Figure 11). As a result, lake flooding is less frequent in the summer than in the spring, ranging from annually for lakes with a sill less than or equal to approximately 2 m asl (20% of all lakes), to 5 years for lakes at 3 m asl. Lakes above 3.5 m asl (33% of all lakes) never received flood water during the summer period over the 12-year record. Since water levels during the summer can fall below 1 m asl (Figure 11), nearly all lakes in the study area can be cut off from the main Mackenzie River channels. Even with a return period of 2 years, water levels can drop to 1.25 m asl, cutting off approximately 90% of the lakes in the study area from the Mackenzie River for at least a brief interval. As a result, there are only a few lakes in the study area which receive both water and sediment from the Mackenzie River for the entire summer period.

As indicated by Figure 11, only a few lakes are "connected" to the Mackenzie River all summer and therefore receive water and sediment from the river. In fact the duration for which main channel water levels are above lake sill elevation varies greatly. The mean duration of the first event of the year (Figure 12a) varies from about 151 days for spring sill levels of 1 m asl to only 3 days for the 5% of lakes with spring sill levels of 5.5 m asl. Since subsequent events (those times when water levels rise above the lake sill after the spring period) are very brief (Figure 12b), the duration of all events combined is very similar to the duration of the first event alone (Figure 12c). In fact, for levels above 3.5 m asl they are identical (i.e. the first event is the only event of the year).

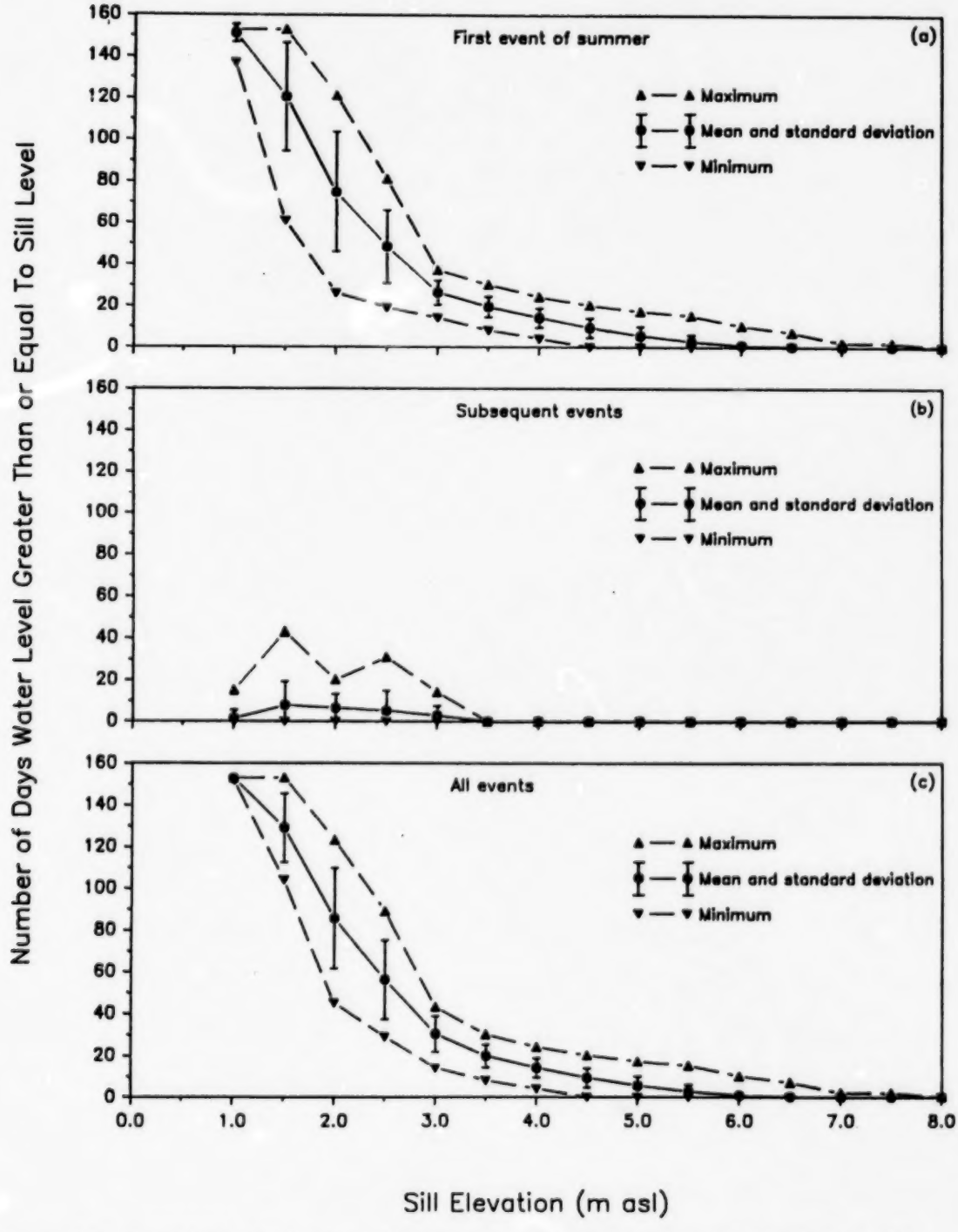

Figure 12. Duration of first, subsequent, and combined events versus sill level.

During the period when main channel levels are above the lake sill elevation, water will flow into the lakes during periods of rising main channel water levels. These inflow events are important to the lake sediment regime, since it is only during this period that sediment is added to a lake. The number of inflows over the summer (Figure 13) ranges from 14 for lakes at 1 m asl to only 1.5 inflows per year at 3.5 m asl, while those at higher levels (4.5 m and above) have less than 1 inflow per year on average. These data however, apply only to delta lakes which have a single channel connecting them to a main channel. NRC and South Lakes are of this type.

6. LAKE SEDIMENTATION

6.1 Lake channel discharge and sediment regime

During the spring break-up period, the water level and sediment regimes of South Channel and Skidoo Channel East are similar. At both sites, the water overtops the low sills in mid-May and flows from Big Lake Channel over the ice blocking the lake channels and into the lake. During this time the discharge into each lake is low but it rapidly increases with rising stage in Big Lake Channel. Initially the suspended sediment concentrations of the water flowing in South and Skidoo East Channels are also low (Figure 14a and 15a), due to the low sediment concentrations in the main channels (Figure 16). However, the sediment

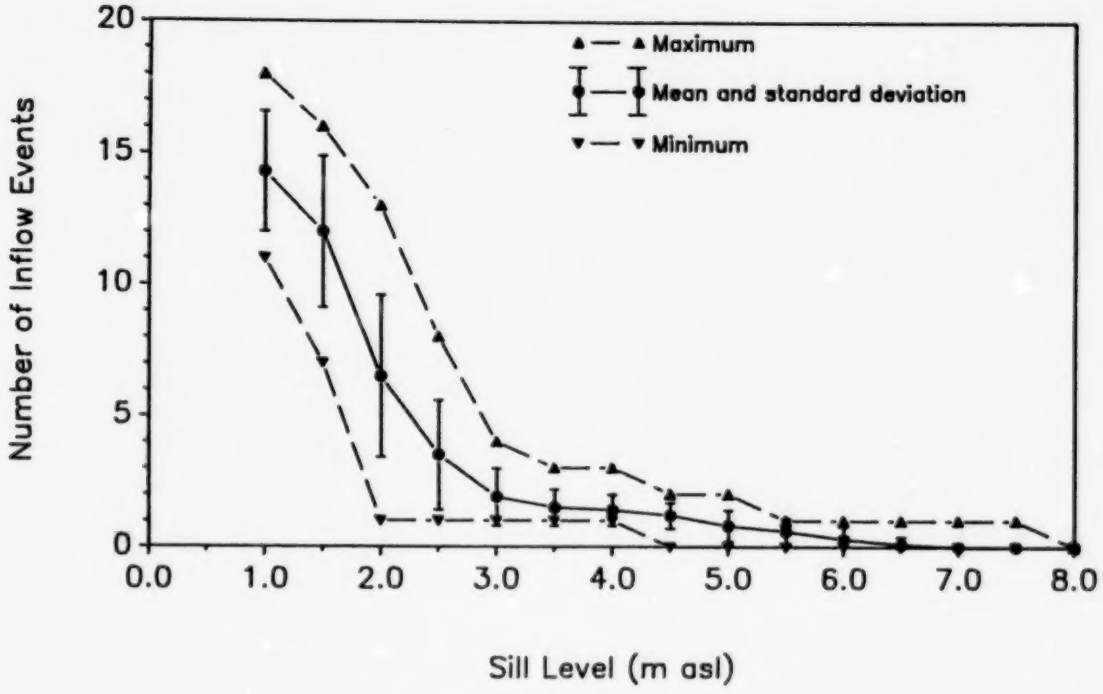

Figure 13. Number of inflows versus sill elevation.

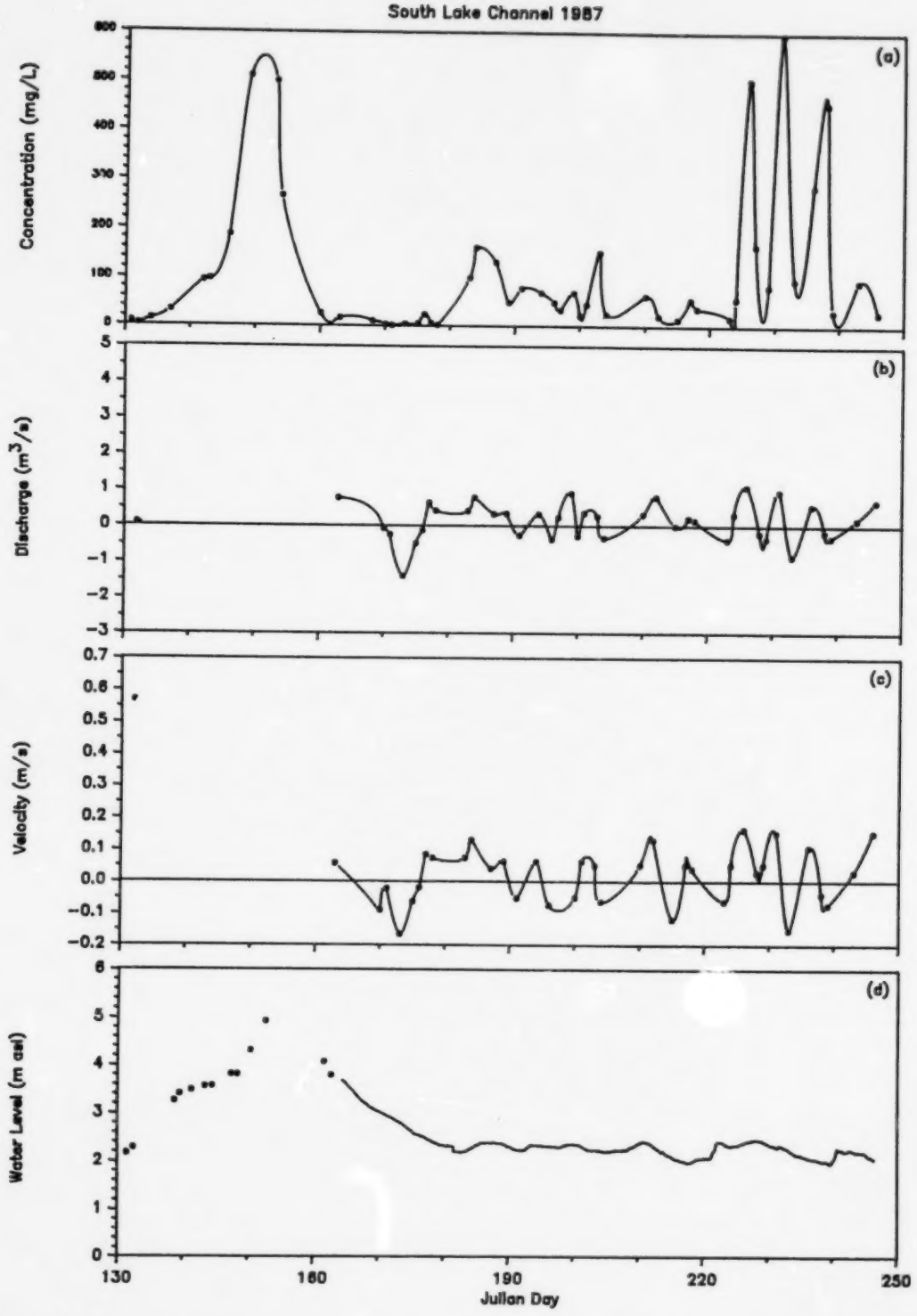

Figure 14. Water level, mean channel velocity, discharge, and suspended sediment concentration for South Lake Channel. Note that positive values are for flow into the lake and negative out of the lake.

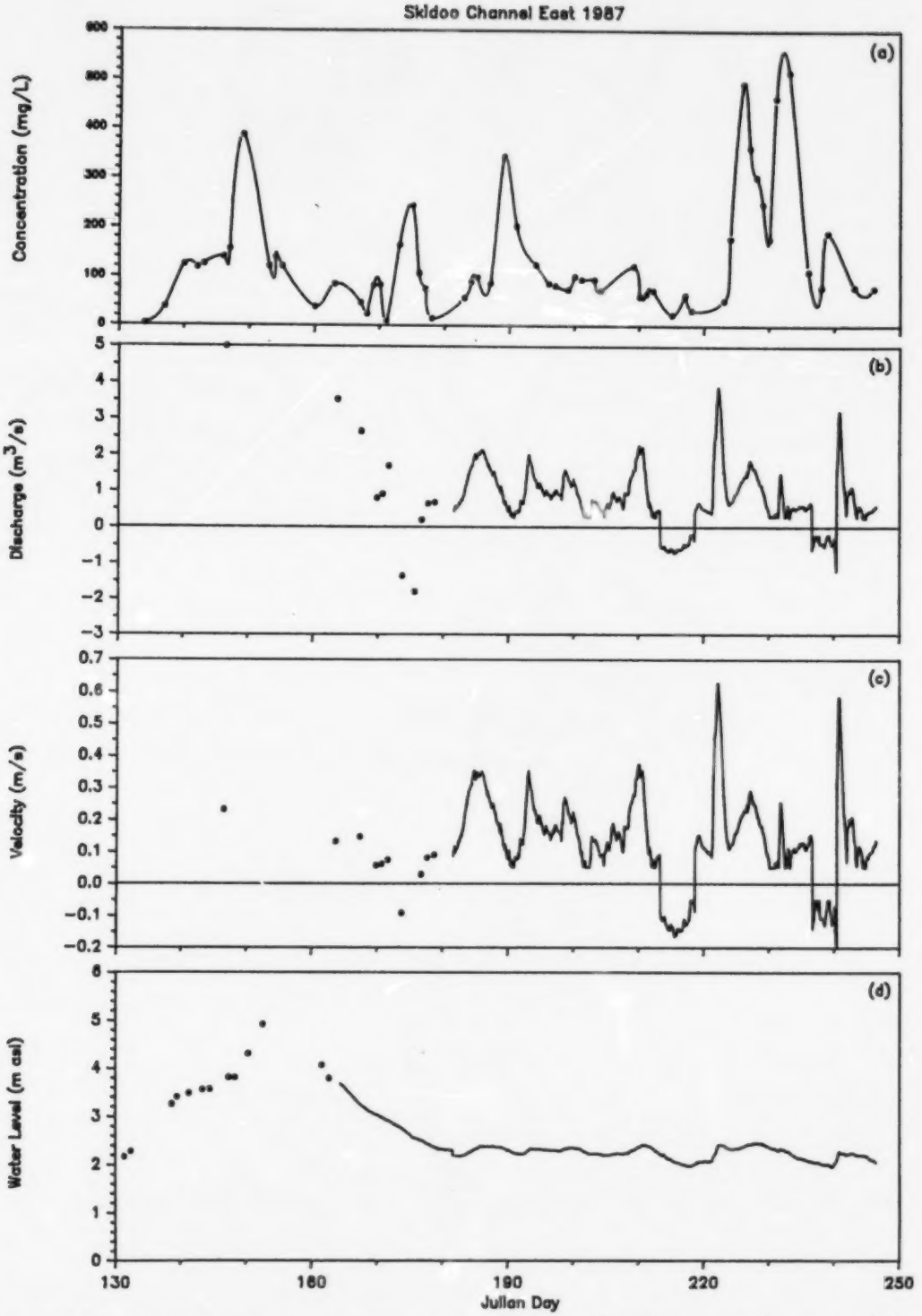

Figure 15. Water level, mean channel velocity, discharge, and suspended sediment concentration for Skidoo Channel East. Note that positive values are for flow into the lake and negative out of the lake.

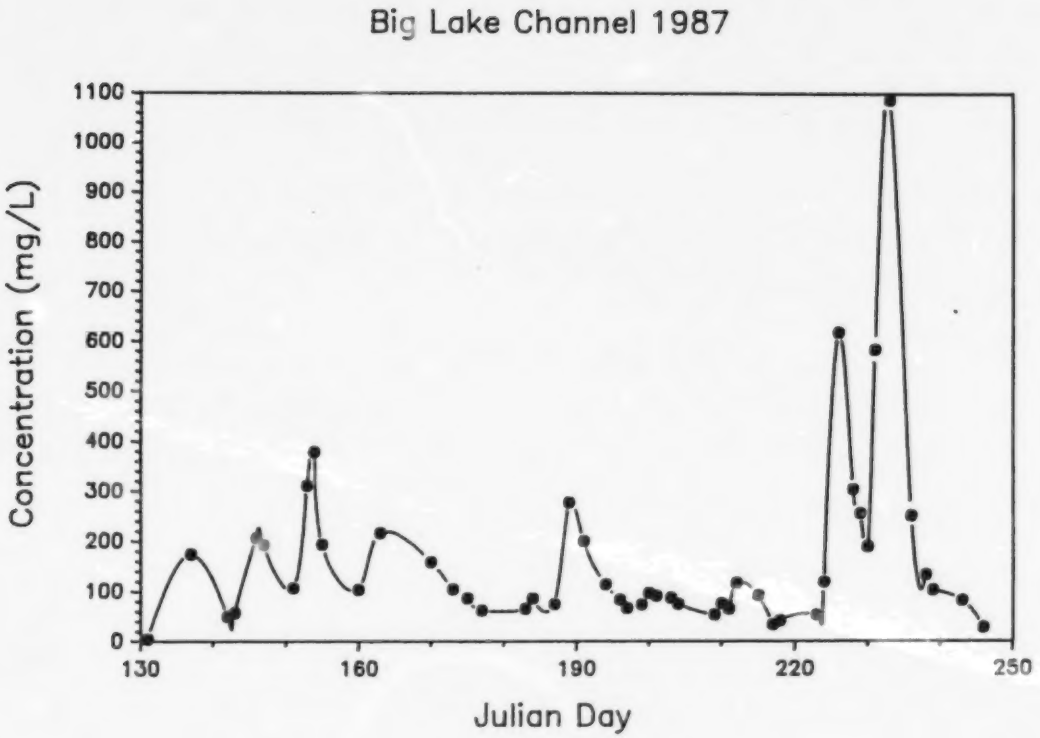

Figure 16. Suspended sediment concentrations in Big Lake Channel, near the entrance to South Lake.

input to the lakes soon begins to increase rapidly as suspended sediment in the main channels rises in response to the rapidly increasing sediment input from the southern portions of the Mackenzie Basin. The peak suspended sediment concentrations during the spring break-up are near the highest of the year, peaking near 550 mg/l in South Lake Channel, and 375 mg/l in Skidoo Channel East. Concentrations are generally lower in Skidoo Channel East than in South Lake Channel because the channel is longer (Figure 1), allowing sedimentation to occur along the channel, prior to the water entering Skidoo Lake.

At both Skidoo East and South Lake Channels, the suspended sediment concentration peaked on May 29, prior to the maximum water level on June 3. A similar observation of the peak suspended sediment concentration occurring prior to the peak water level was observed in the Colville River Delta by Arnborg et al. (1967). This is due primarily to changes in the sediment supply during the period of rapidly rising water levels.

During the period of rising stage in the spring, water is flowing out of Skidoo Lake and through Skidoo Channel West into the other lakes in the Skidoo system. Due to its distance from a main channel and settling of sediment in Skidoo Lake, Skidoo Channel West has a lower suspended sediment concentration than Skidoo Channel East (Figures 17a and 15a).

After the peak water level is reached, water levels drop dramatically (Figures 14d, 15d, and 17d), with resulting discharge out of the lakes. For South Lake, water is simply discharged out of South Lake Channel. For Skidoo Lake, water generally continues to flow into the lake through Skidoo East, with larger discharge out of Skidoo West (Figures 15b and

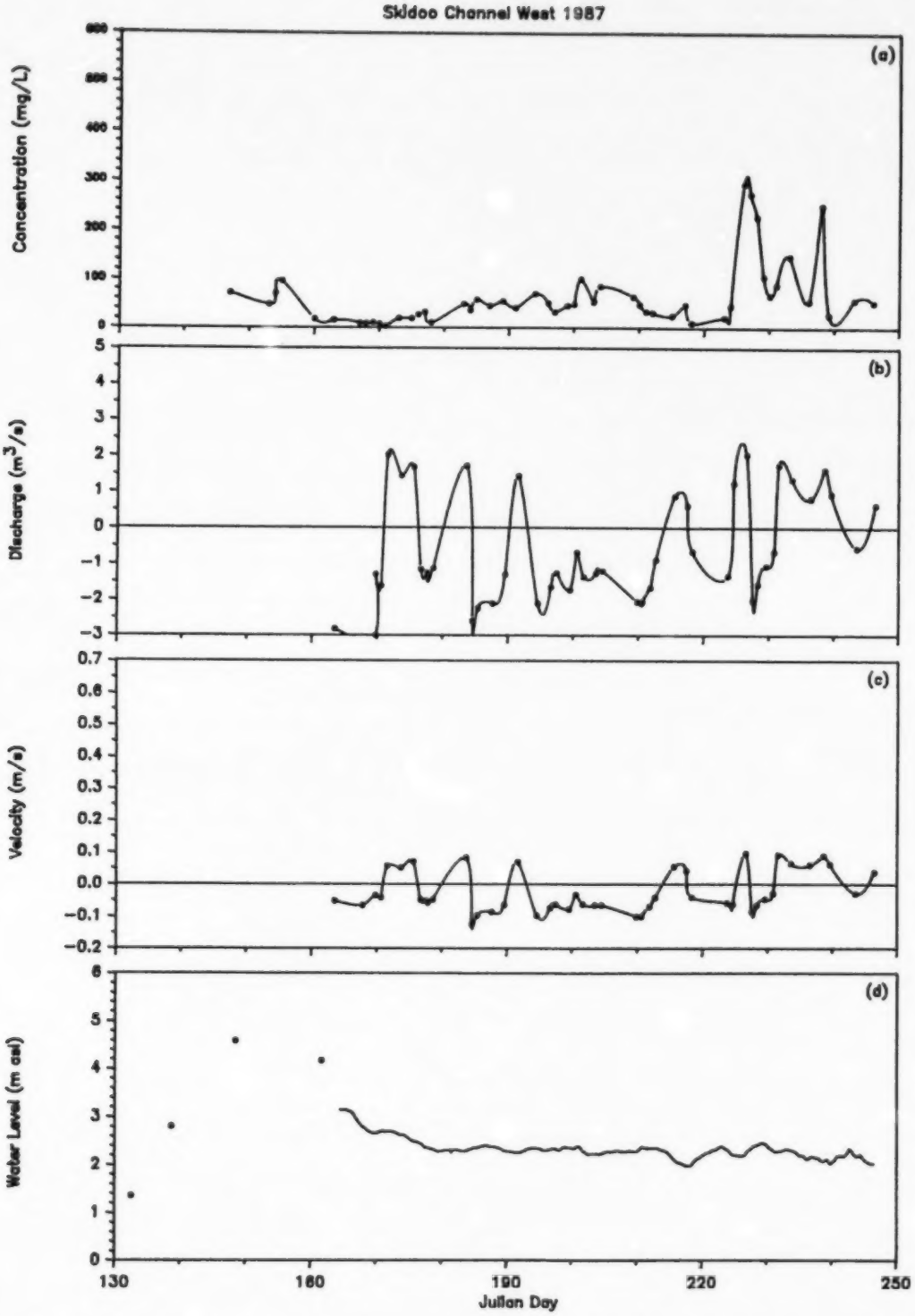

Figure 17. Water level, mean channel velocity, discharge, and suspended sediment concentration for Skidoo Channel West. Note that positive values are for flow into the lake and negative out of the lake.

17b). During this period of falling water levels, the suspended sediment concentrations also decline rapidly (Figures 14a, 15a, and 17a).

During the remainder of the summer the discharge regime of South and Skidoo Lake Channels is dominated by small fluctuations in the water level of Big Lake Channel. However, the two lakes respond very differently. Since South Lake is connected to Big Lake Channel by a single channel, it responds quickly to changes in main channel level, with rapid changes between positive and negative discharge (Figure 14b). During the 1987 season there were 10 inflow events to South Lake. This is approximately normal for lakes with the sill elevation of South Lake (Figure 13).

Skidoo Lake also responds to changes in Big Lake Channel levels, with rapid changes in velocity and discharge (Figure 15c,b). However, the flow is generally into the lake through Skidoo East, and with discharge in Skidoo West fluctuating between into and out of the lake (Figure 17b). In Skidoo Channel East there were only a few negative discharges during periods of low water (Figure 15d). A total of only 4 inflows through Skidoo Channel East is considerably different from that occurring in South Lake, even though Skidoo Lake has a sill elevation similar to South Lake.

The complexities of the discharge regime of the Skidoo Lake system are illustrated in Figure 18. On June 18, the flow was from Big Lake Channel into Skidoo Lake and then out through Far Lake. Discharge was also out of the lake system to the south. On August 11 flow was in the same direction through Skidoo Lake, but note that flow directions had reversed at the other two channel sites. Later in the summer (September

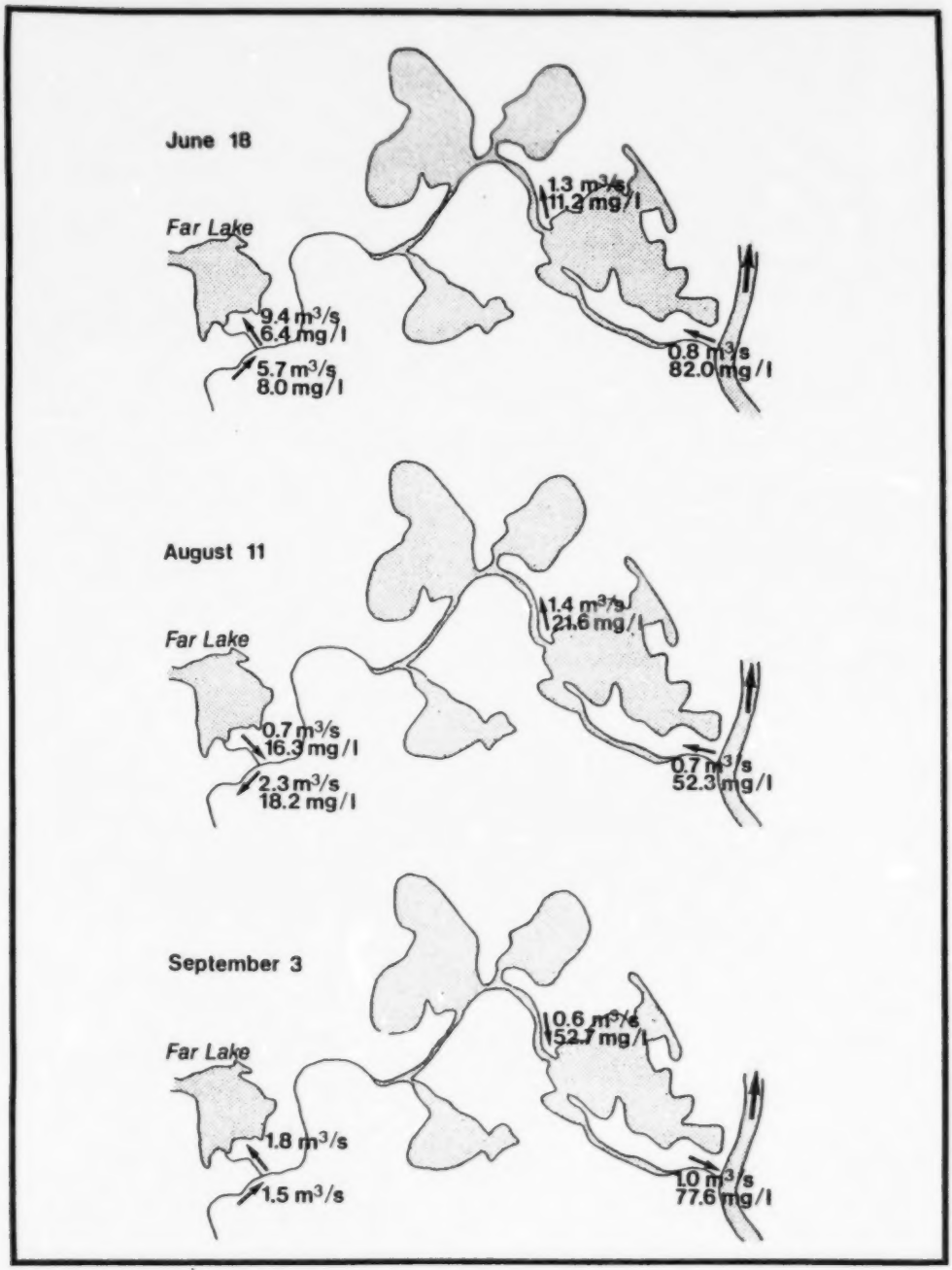

Figure 18. Discharge and suspended sediment concentrations in the Skidoo Lake system.

3) flow reversed in Skidoo Channel East and West, but the other two sites remained as they were on June 18. These data illustrate the complexity of the Skidoo Lake system, with flow directions in Skidoo East and West controlled not only by Big Lake Channel water levels, but also by levels in the lakes within the system, and by East Channel and Rabbit Ears Channel. Since the channel water levels have very low slopes, it is difficult to measure the changes in levels responsible for these fluctuations in discharge. As a result, flow directions are difficult to predict. However, the general pattern is shown in Figure 19 for the spring peak rising and falling stages, the summer period, and the fall period. This pattern of flow for Skidoo Channel East and West is similar to that observed in 1987. Also shown in Figure 19 are the discharge patterns of South and NRC Lakes.

In conjunction with these variations in discharge during the summer period, there were also large fluctuations in suspended sediment concentrations in South and Skidoo Lake Channels (Figures 14a, 15a, and 17a). Flow into the lakes generally had higher suspended sediment concentrations due to the effect of the main channels, while the flow out of them had lower values due to settling of sediment in the lake basins. The general pattern is the same for South Lake and Skidoo East and West, with values fluctuating between 2 and 300 mg/l during much of the summer. Later in the summer, suspended sediment increased dramatically during August (days 226 to 232) (Figures 14a, 15a, and 17a) with peak suspended sediment values of 516 mg/l in Skidoo Channel East. During this period, water levels only increased slightly (Figures 14d, 15d, and 17d).

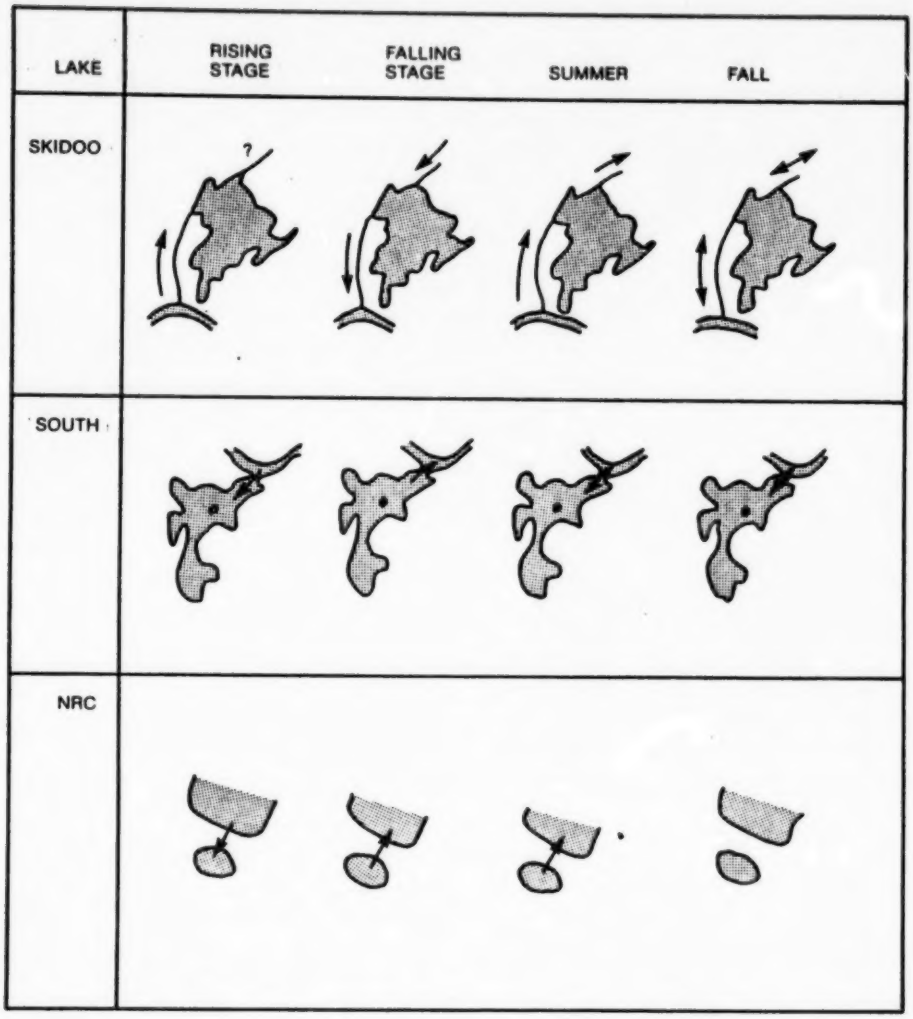

Figure 19. Flow directions in South, Skidoo and NRC Lake Channels in 1986.

In addition to these temporal fluctuations in suspended sediment concentrations, there were large spatial variations within the Skidoo Lake system. For example, suspended sediment concentrations decrease within the Skidoo Lake system with increasing distance from Big Lake Channel (Figure 18). This suggests that sedimentation rates decrease with increasing distance from the main channel.

The discharge and sediment regime of NRC Lake is different from both Skidoo and South Lakes in two respects. First, the sill of NRC Lake limits the flooding of the lake to maximum flood stage only (Figure 20). Discharge is therefore simply into the lake during the rapid rise in levels in the spring and then out of the lake during the remainder of the summer, with discharge ceasing in mid-summer (Figure 20b). Thus sediment is transported into the lake only during the brief period of rising stage in the spring. Second, NRC Lake is the last lake in a series of lakes. The lake therefore does not receive flood water directly from a main distributary. Thus the suspended sediment concentration of the water entering NRC is considerably lower. For example, peak suspended sediment concentration was only 50 mg/l (Figure 20a), compared to over 500 mg/l at South Lake.

Bedload measurements in Skidoo Channel East showed no movement during the late August period. Since channel velocities at this time were near maximum values for the summer (Figure 15c), it is assumed that bedload movement in the study channels was negligible throughout the spring and summer periods. As a result the bedload term in equation 1 is assumed to equal zero.

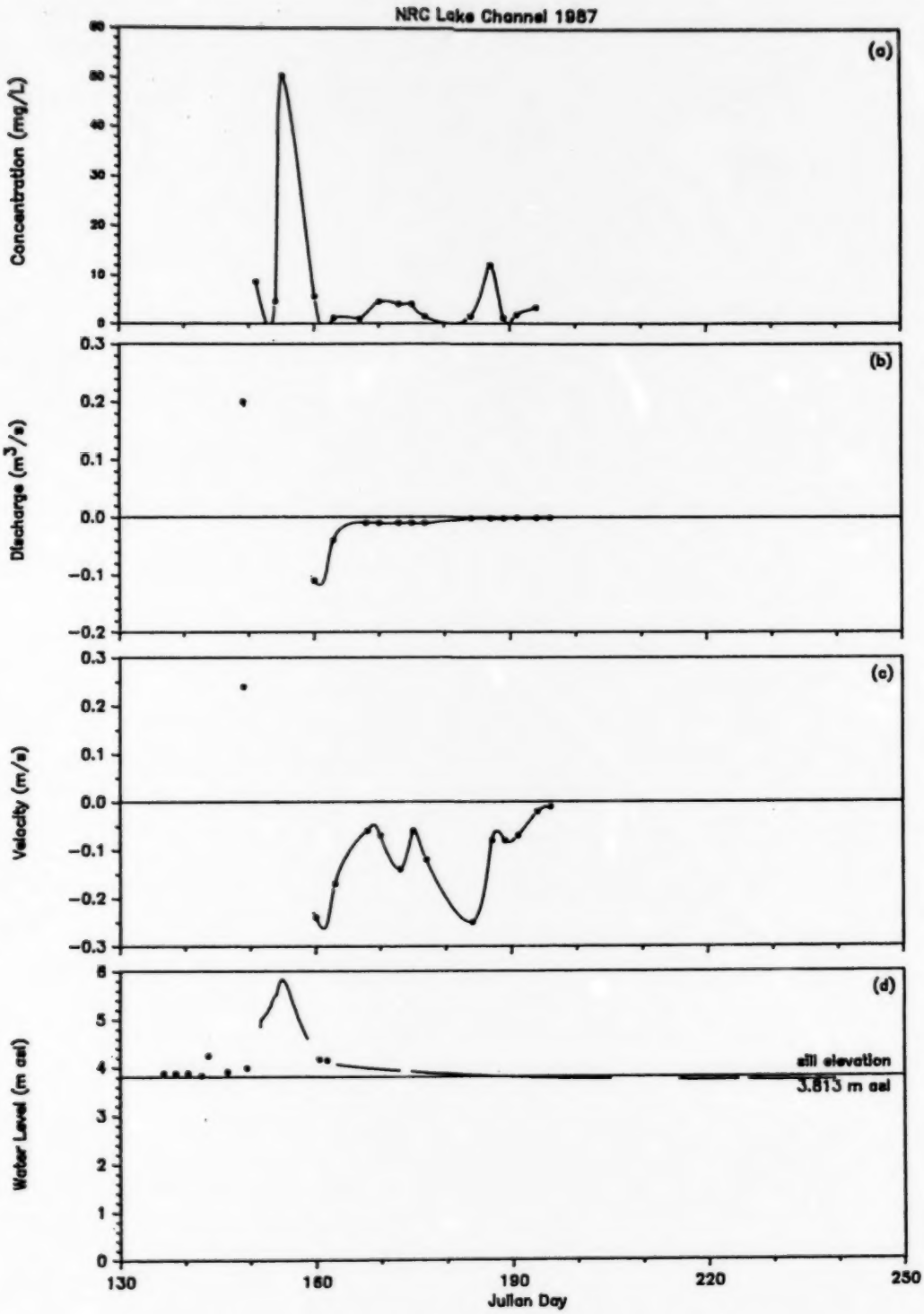

Figure 20. Water level, mean channel velocity, discharge, and suspended sediment concentration for NRC Lake Channel. Note that positive values are for flow into the lake and negative out of the lake.

6.2 Lake sediment budget and sedimentation rates

The sedimentation regimes of each of the study lakes are considerably different as is shown by the cumulative loads for each lake (Figure 21). South Lake has the largest load over the May 11 to September 3 study period, totalling approximately 550 Mg, or 1.3 mm distributed over the lake area (Table 3). The majority of this sediment (61%) is deposited within the lake during the brief spring flood. The remaining load is deposited at a fairly slow but uniform rate during the summer period. A significant increase in suspended sediment concentration (Figure 14a) in August resulted in approximately 30% of the total summer input of sediment (Figure 21).

Skidoo Lake on the other hand had a smaller load of approximately 300 Mg or .5 mm over the lake area (Figure 21, Table 3). The spring peak is again the major event of the summer, representing 72% of the total load transported into the lake. The remainder of the summer, however, is considerably different from that for South Lake, with more fluctuations in load (Figure 21). These differences occur because South Lake has a single, short channel connecting it to the main distributary, while Skidoo Lake is some distance along a winding channel. In addition, as discussed earlier, Skidoo Lake is part of a large connected lake system. The resulting differences in flow conditions result in the observed variations in sediment influx. For example, South Lake experiences frequent flow reversals, while in the Skidoo Lake system most material moving in through Skidoo Channel East moves out through Skidoo Channel West and on to the other lakes along Skidoo Channel. As was the case for

Table 3. Sedimentation rates for Skidoo, South and NRC Lakes for May 11 to Sept. 3. Also shown is a comparison of the sedimentation rates determined from the sediment balance and the sedimentation plates for June 24 to August 31.

	Sediment Budget		Sedimentation Plate *	
Lake	Date	Depth (mm)	Date	Depth (mm)
South	May 11-Sept. 3	1.3	--	--
	June 24-Aug. 31	.5	June 24-Aug. 31	.5
Skidoo	May 12-Sept. 3	.5	--	--
	June 24-Aug. 31	.2	June 24-Aug. 31	.4
NRC	May 12-Sept. 3	.02	May 16-July 10	1.1

* NOTE: Sedimentation plate values are:

(1) weighted for area to determine a mean value of Skidoo and South Lakes;

(2) value for NRC is the mean for 2 sedimentation plates located in the centre of the lake.

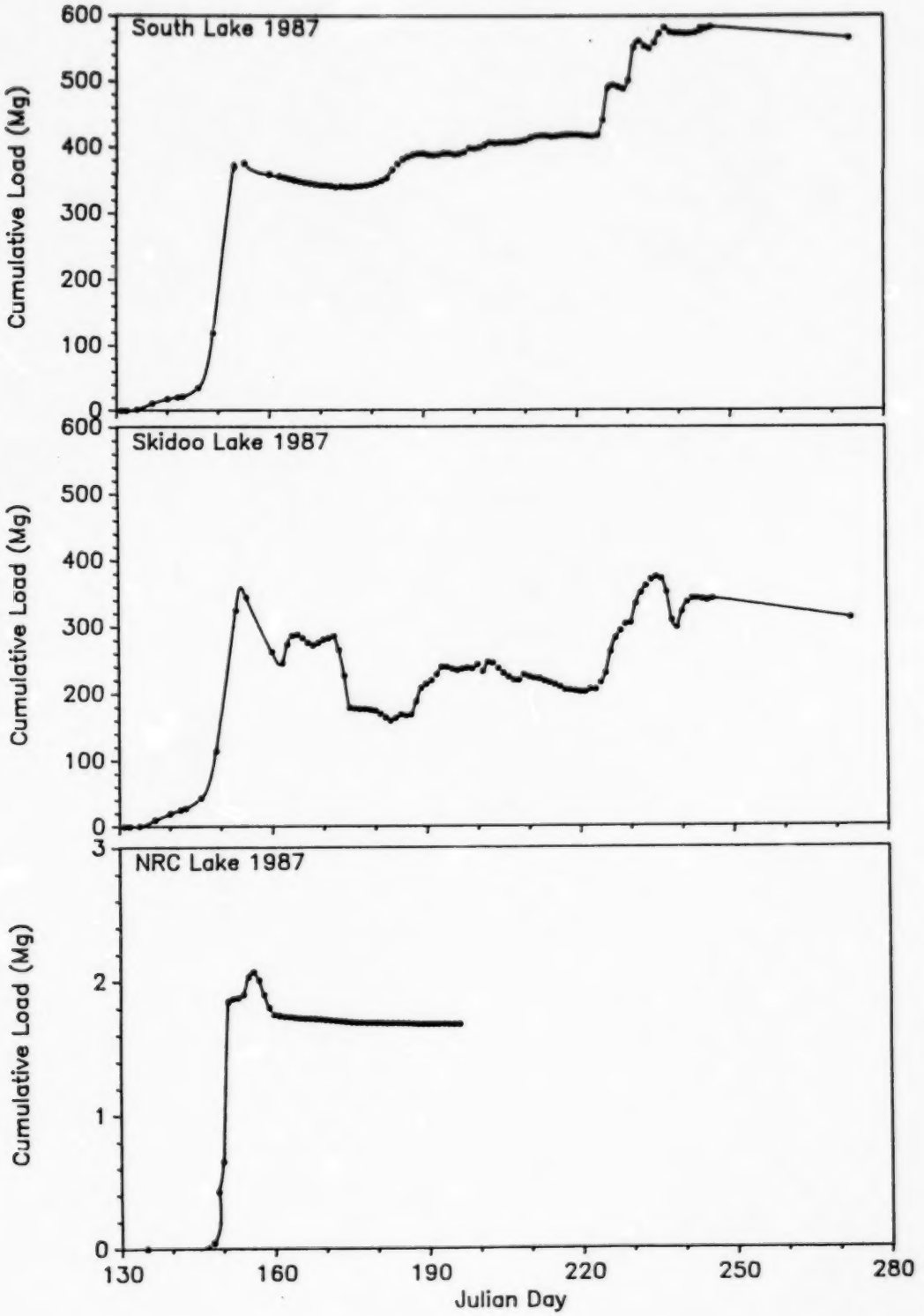

Figure 21. Cumulative sediment load to South Lake, Skidoo Lake and NRC Lake in 1987.

South Lake, there was a significant sediment event during August (Figure 21).

NRC Lake has a very different cumulative load compared to either of the other two lakes. The total load is slightly less than 2 Mg or .02 mm over the lake area, or 2 orders of magnitude less than South and Skidoo Lakes. This is primarily due to the high sill elevation of NRC Lake, which limits floodwater entering NRC Lake to the spring break-up period. As a result, 100% of the year's influx of sediment enters the lake during a short 10-day period in the spring (Figure 21).

An estimate was made of the total load lost from the end of the study period (September 3) to freeze-up in early October (day 275). It was assumed that the water level at freeze-up was equal to the sill elevations of South and Skidoo Lakes and that the suspended sediment concentration on September 3 was representative. The resulting estimated loss in sediment is small and does not significantly change the annual sediment balance (Figure 21).

Errors in the sediment budget calculations are not known, but an estimate of the errors involved can be seen by comparing the sedimentation rates calculated from the sediment budget and the sedimentation plates for South and Skidoo Lakes over the period June 24 to August 31. As shown in Table 3, they are in general agreement. The two estimates for South Lake are identical, while for Skidoo Lake the sedimentation plates gave a value twice as large as that determined by the sediment budget. The reasons for this are not known. The large difference in sediment budget and sedimentation plate depth for NRC Lake (Table 3) is probably due to the fact that only two sedimentation plates

were used in NRC Lake. As a result, the spatial distribution of sediment is not known, and the sedimentation budget is probably more accurate than the estimate derived from the sediment plates.

6.3 Spatial pattern of sedimentation

Within the study lakes there are visual differences in sedimentation. Sedimentation observed along Skidoo Channel East varies from one to two cm/a, while the sediment deposited on the leaf litter on the banks of a small bay of the lake is less than 1 mm. The most striking evidence within the lakes, however, is the development of small deltas which are apparent in both Skidoo and South Lakes. The field methods employed during the 1987 field season attempted to quantify this differential sediment movement within the three study lakes and along lakes connected to Skidoo Lake Channel.

Using the data from the sedimentation plates, Figures 22 and 23 show the measured sedimentation rates within Skidoo and South Lakes over the period June 24 to August 31, 1987. These data are therefore just for the summer period and do not include sedimentation during the spring flood period. The important aspect of this data, however, is not the absolute magnitudes, but the variability in sedimentation.

In both South and Skidoo Lakes the maximum deposition is close to the entrances of the channels to the lake, with typical values as high as 3 to 5 mm recorded. This zone of rapid sedimentation represents the area of lake delta growth. With increasing distance from the lake deltas, sedimentation decreases (Figures 22 and 23) from .1 mm in the middle

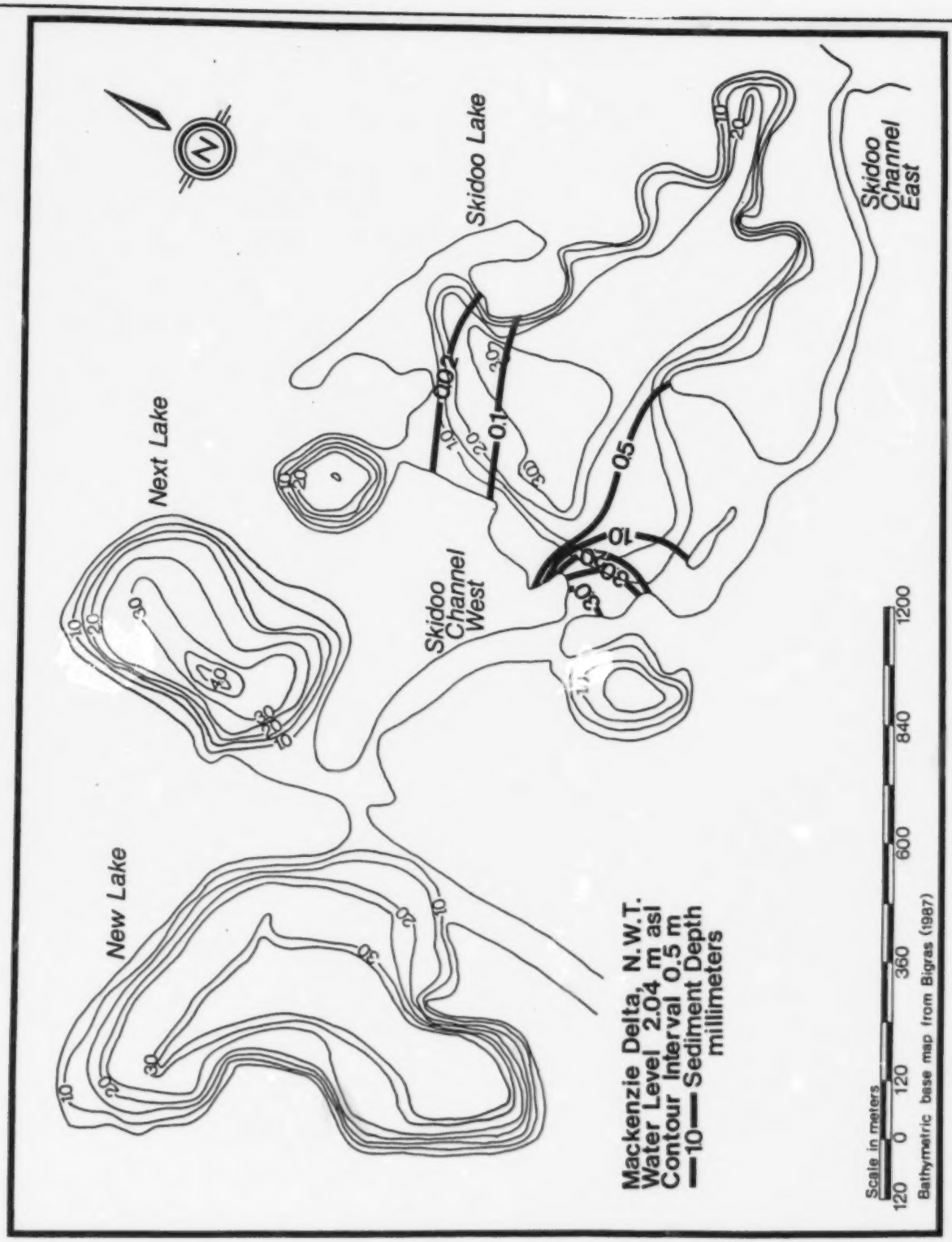

Figure 22. Sedimentation rates within Skidoo Lake as determined from the sedimentation plates.

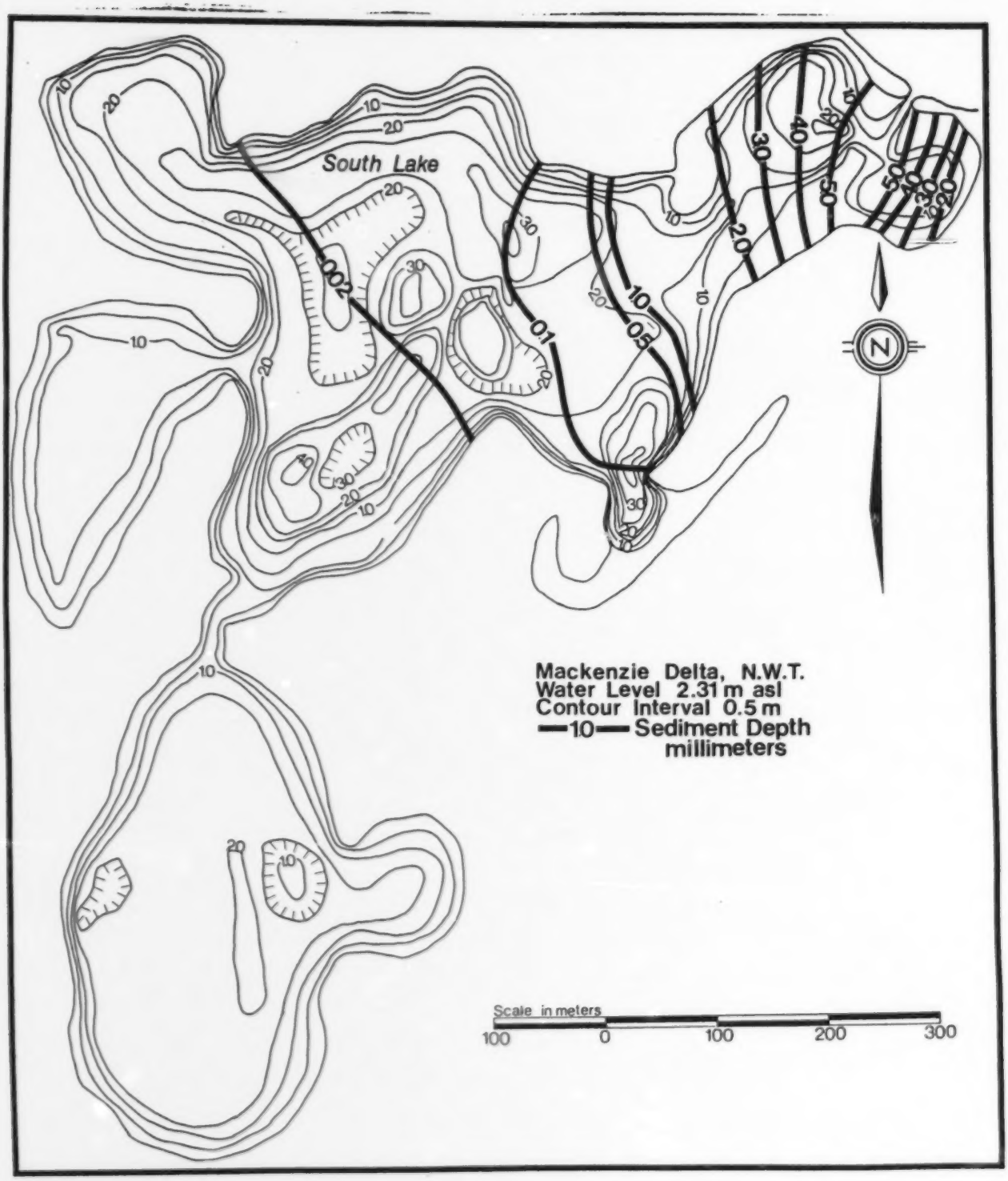

Figure 23. Sedimentation rates within South Lake as determined from sedimentation plates.

portions of the lakes to only .02 mm in the isolated bays. This large spatial variation demonstrates the problems with determining mean lake sedimentation from single core samples dated using the ^{137}Cs method. Great care must be taken to choose locations which are representative.

There are also large variations in sedimentation rates within lake systems. Limited data from Next and New Lakes (Figure 22) show rates of between 1 and 2 mm in areas near the channel entrances. This decrease in sedimentation compared to near the mouth of Skidoo Channel East is due to increased distance from Big Lake Channel. The rapid decrease in sedimentation with increasing distance from the main channel is also evident from decreased suspended sediment concentrations (Figure 18), and from air photos, where high suspended sediment concentration shows as lighter coloured water (Figure 2).

Spatial variation within lake systems is also influenced by lake sill elevation. This is illustrated by comparing NRC and South Lakes, both of which have single connecting channels, but South Lake has a much lower sill than NRC Lake. The resulting difference in discharge regime (Figures 14 and 20) results in much lower sedimentation rates for NRC Lake (Table 3). In general, there should be a good relationship between sedimentation rate and lake sill elevation, however, it will be complicated by the distance from a main channel.

The particle size distributions (D_{90} particle diameter) of the material on the sedimentation plates and from lake bed samples are shown in Figures 24 and 25 for South and Skidoo Lakes. In general, the material was silt/clay (less than .0625 mm) with only a small amount of fine sand in some of the samples. The coarsest material occurs near the

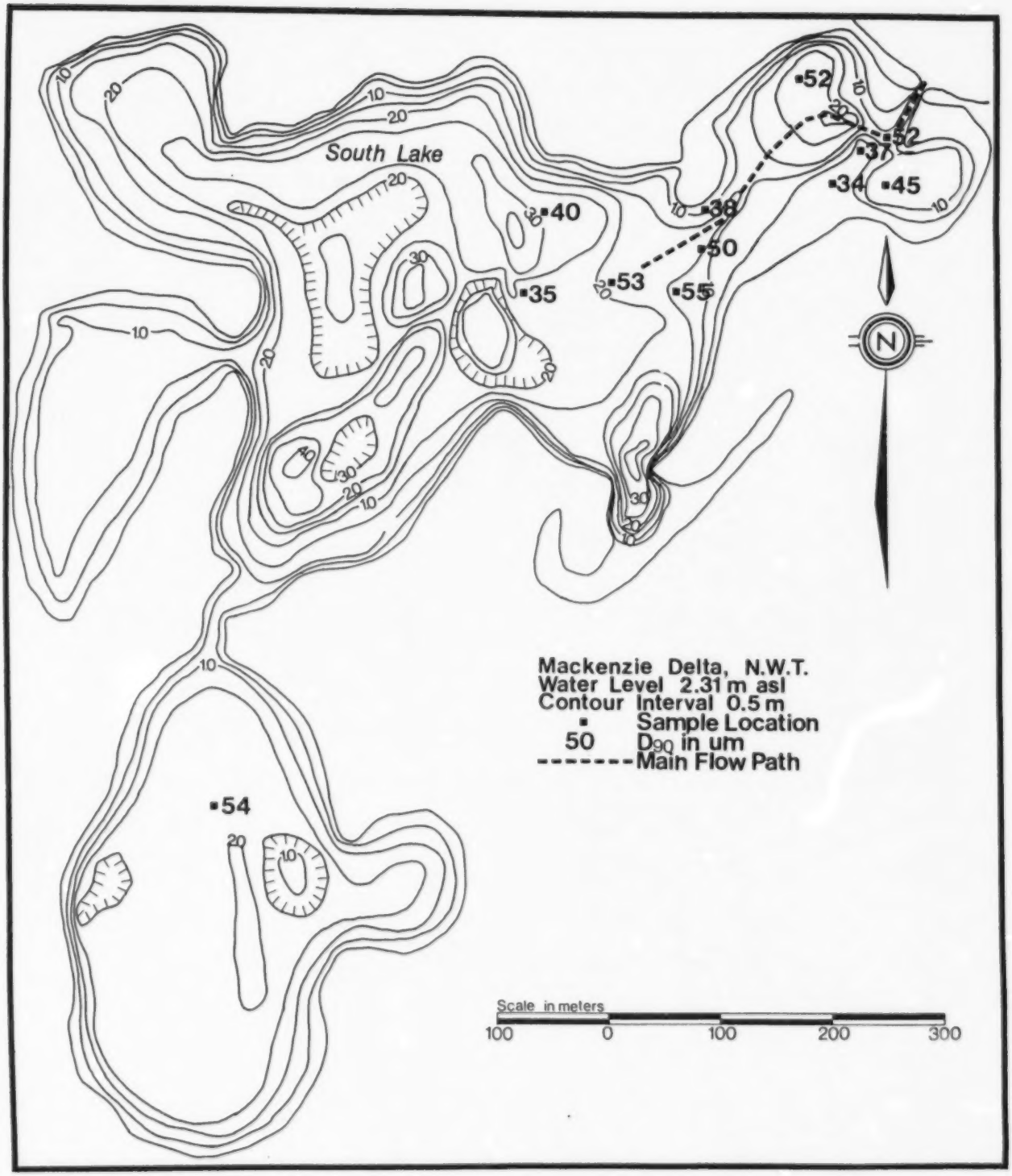

Figure 24. Grain size (D90) of the material collected on the sedimentation plates and from bed samples in South Lake.

Figure 25. Grain size (D90) of the material collected on the sedimentation plates and from bed samples in Skidoo Lake.

lake deltas, with the finer materials in the outer parts of the lakes. The coarsest particles tend to occur in areas within the lakes which have stronger flow velocities.

7. DISCUSSION

Variations in the sediment regime of delta lakes have a number of implications from the transport and deposition of hydrocarbons in the Mackenzie Delta. Certainly the data show significant amounts of sediment are entering delta lakes. For example, over the 1987 study period, 584 Mg of sediment were deposited in South Lake. This large amount of sediment has a major impact on the physical and biologic conditions in the delta lakes. For example, sedimentation in the lake delta areas controls the lake sill elevation and therefore the hydrologic regime, and the input of nutrients associated with the sediments have an important effect on the biological productivity of the lakes. Although there is little available data, this input of sediments to the lakes should influence the deposition of hydrocarbons in the lakes.

The sediment data presented in the earlier sections of this report allow a few remarks to be made concerning the introduction of contaminants adsorbed onto sediment and the deposition of these contaminants in delta lakes. First, and most importantly, the sediments entering the lakes are silts and clays, which have a high sorptive capacity for contaminants. It would be expected, therefore, that

contaminants in the Mackenzie system would end up in the delta lakes. Of the sediments entering the lakes, results from the present study have shown that between 47 and 88% are deposited within the lake. The remainder flow out of the lakes and back into the main channels. As a result, a high percentage of all hydrocarbon contaminants entering the lakes would be deposited within them.

There are large spatial variations in the deposition of this sediment, with most deposited near the lake channel mouth. In Skidoo and South Lakes, for example, 57 and 53% of all sediment was deposited in only 20 and 6% respectively of the lake area. This suggests that most contaminants would also be deposited near the channel mouths. But since finer particles are deposited in the areas of the lake farther away from the channel entrances and since they are more efficient in carrying contaminants, a larger percentage of all contaminants may be deposited over larger areas of the lake than is suggested by the sediment data alone.

In large lake systems like the Skidoo Lake system, much of the sediment is passed directly through the first lake within the system. 87% of sediment entering Skidoo Channel East during the summer period passes through the first lake. Thus most contaminants would be distributed into other lakes in the system. This sediment is then deposited in a large number of lakes. Therefore, the actual sedimentation rate in each lake may actually be quite small.

There are also large temporal variations in sediment deposition. In South Lake, about 67% of all sediment was deposited during the spring break-up period. Since we do not have similar data on the temporal

variation in hydrocarbon levels, we cannot determine the effect on contaminant deposition within the lakes.

The large temporal variations in sediment deposition indicate that the effect of future hydrocarbon spills would depend very much on the timing. Since hydrocarbons can enter a lake only if the channel level is above the lake sill, spills during the spring high-water period would affect the greatest number of lakes, while spills later in the summer, when water levels are low, would affect only a few lakes. These low water events could still be important, however, since the few low sill elevation lakes are large in area.

Though the data show that large amounts of sediment are deposited in these delta lakes, we have no information on the levels of hydrocarbons associated with these sediments. However, a rough estimate may be made using the data from Nagy et al. (1987) of .773 and .289 $\mu g/g$ of sediment for n-alkanes and PAHs in East Channel at Inuvik. Assuming that these point estimates are representative of the summer period, the input of hydrocarbons to the study lakes was 2, 363, and 620 g for NRC, Skidoo, and South Lakes respectively in 1987. This corresponds to levels of 25, 961, and 996 $\mu g/m^2$ for NRC, Skidoo, and South Lakes respectively. Due to the limited data set, the representativeness of these estimates is not known.

The results discussed in this report are very preliminary and conclude there is a need for further studies. Most importantly, at least two more year's of data are required to obtain an appreciation of the variability of sedimentation from year-to-year. In order to determine the effect of distance along a lake system and lake sill elevation on

sedimentation rates, more lake coring and ^{137}Cs dating are required. However, before this technique provides reliable data on mean lake sedimentation, more information is required on the spatial variation of sedimentation within lakes. In addition, similar data are required in other areas of the delta where the hydrologic and sedimentary regimes are considerably different. Finally, measurements of the hydrocarbons adsorbed onto the sediment entering the delta lakes and deposited on the lake beds is required to substantiate the estimates of background levels in these delta lakes.

Future work should also be aimed at linking the hydrologic and sedimentary regimes in order to improve our ability to predict lake sedimentation regimes. This could have important implications for determining the input of hydrocarbon contaminants to delta lakes.

8. CONCLUSIONS

(1) The hydrologic and sediment regimes of the study lakes varied considerably. Skidoo and South Lakes were characterized by fluctuating discharge over the entire summer period and high suspended sediment concentrations. While NRC Lake received discharge only during the spring flood due to its higher sill elevation and had considerably lower suspended sediment concentrations.

(2) Mean annual sedimentation rates for 1987 were .02, .5, and 1.3 mm for NRC, Skidoo, and South Lakes respectively. These are lower than rates reported for similar lakes elsewhere in the Mackenzie Delta.

(3) A comparison of the sediment budget and sedimentation plate methods for determining mean sedimentation rates showed that the two methods were in close agreement over the summer. This suggests that the sediment balance method provides accurate results for the annual budget.

(4) Sedimentation rates within lakes and within lake systems varied considerably over the summer period after the spring break-up. At South Lake, for example, the rates varied from 5 mm near the lake channel entrance, to only .02 mm in isolated bays. In total, 53% of all the sediment was deposited in only 6% of the lake area.

(5) The spring flood period is the major sedimentation event of the year. At South Lake, 67% of all sediment was deposited during this period. Significant sedimentation can occur during brief periods of high suspended sediment concentrations in the summer.

(6) The particles deposited within the lakes are primarily silts and clays, with the finest particles deposited farthest from the channel entrances.

(7) Due to the long settling times associated with these fine-grained suspended sediments, only 47 to 88% of all sediment entering the lakes is actually deposited in the lakes. The remainder flows back out of the lakes and into the main channels.

(8) Using published values for n-alkanes and PAHs in the suspended sediment of East Channel at Inuvik, the input of hydrocarbons to the

study lakes was estimated as 2, 363, and 620 g for NRC, Skidoo, and South Lakes. This corresponds to 25, 961, and 996 $\mu g/m^2$ of lake bed.

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